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WAVE ENERGY STUDY

NEL OSCILLATING WATER COLUMN

100 MW POWER STATION

2ND INTERIM REFERENCE DESIGN

for

Department of Energy

Report No. PR2: Y5/DEY/2 July 1978

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Department of Industry

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COMMERCIAL-IN-CONFIDENCE

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JULY 1978

SUMMARY:

An interim reference design for the NEL Oscillating Water Column has been developed to the stage where construction in reinforced concrete or structural steelwork is practicable, using existing or developed technology. This is described together with a philosophy for operation and maintenance.

Lithgows Limited, Port Glasgow, contributed the study of the construction of the reference design in steel.

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DEFINITIONS AND ABBREVIATIONS:

Module	One Oscillating Water Column and its attendant housing
Reference Design	A basis for comparison for further development and refinement work
Rode	The complete assembly of a mooring line including all ropes and shackles
Unit	A floating structure containing a group of 6 Oscillating Water Columns
AVR	Automatic Voltage Regulation
GRP	Glass Reinforced Plastics
MCR	Maximum Continuous Rating
OWC	Oscillating Water Column
OWS	Ocean Weather Ship
SLS	Serviceability Limit State
TAG	Technical Advisory Group
ULS	Ultimate Limit State
VIGV	Variable Inlet Guide Vanes

CHAPTER 1 - GENERAL DESCRIPTION:

Description of the Structure

The NEL Oscillating Water Column device extracts energy from the waves as follows:

1. Primary System:

   A column of water is induced to oscillate by wave action and its motion is used to pump air through the secondary system.

2. Secondary Conversion System:

   (a) The air flow is rectified by louvre non-return valves to a unidirectional flow;

   (b) This air flow drives a reaction turbine, which, in turn, drives an electric alternator;

   (c) Produced AC is collected from the alternators and rectified for transmission to shore as DC.

Six water columns with associated secondary equipment are housed in a floating unit constructed in either concrete or steel. Twenty five floating units make up the 100MW Power Station.

This reference design has been developed in order to provide a basis of comparison for future developments and refinements.

Description of the Structure contd.

The NEL Oscillating Water Column device has been tank tested in a wide tank using various numbers of individual water columns. For the purpose of further study, a floating unit consisting of six columns was selected as giving good prospects for performance combined with reasonable size for construction and mooring. This is the configuration which is now presented as the interim reference design. It is a compact and rigid structure, with inherently good survival characteristics due to its ability to 'ride the punch' in extreme conditions. A longer unit would suffer greater structural loading and have a tendency to force the end columns under the water with the risk of flooding the turbine.

Various shapes of cross section of the device were tested in a narrow tank and the one chosen for the reference design in concrete, whilst not the most efficient, was the practical shape which was thought to give an acceptable overall efficiency. This was a rectangular shape 35m wide, with a draft of 25m when at rest. Thus, the concrete reference design floating unit consists of six water columns of 12m x 18m cross section, forming a box 116m long x 35m wide and 30 - 35m high. In order to give the structure long life in the corrosive marine environment with a minimum of maintenance, ancillary structural steelwork has been kept to a minimum and been confined to the upper parts of the machinery space and the air ducting. It may be possible to replace even some of this with glass reinforced plastics.

For the reference design in steel, the cross section adopted was that of the model which gave the best overall efficiency in the tank tests. This reference design has not, however, been optimised from the point of view of construction. The overall dimensions for the steel reference design are 121.5m

Description of the Structure contd.

long x 35m wide x 33m high (see Appendix 'B' for test summary).

The structures will be moored using a tensioned system with conventional anchors, clump weights, and mainly man-made fibre ropes in preference to wire or chain, thereby providing sufficient elasticity to eliminate snatch forces.

The structures will lie in an approximately north-south line off the West Coast of Britain at a spacing of approximately 540m centre to centre, i.e., a clear space of some 400m between each structure, which could permit small craft to pass through between the units. The total length of the line of the 25 units needed for 100MW output is 13.5Km.

It is not thought advisable to have the structure continuously manned due to its constant motion and low profile in the waves. Accordingly, the systems of operating and maintenance have been designed on the basis of remote control and servicing by imported crews as necessary. Control is from the shore by subsea control cable backed up by radio link.

CHAPTER 2 - STRUCTURE:

Two concepts of the structure are presented. The 'base case' has been taken as a concrete construction and the design developed around this (Drgs. Nos. 1 and 2). At the same time, a structural steel unit having similar output capacity has been designed and documented by Lithgows Limited, Port Glasgow, in the form of a Pilot Study, using their shipyard facilities, (Drgs. Nos. 5, 6, 7, 8 and 9).

(a) Concrete

Description of Structure and Philosophy of Design

The reference design structure is a long rectangular box (116m x 35m, 30-35m high), divided by stiff cross walls into six sections, each of which contains a water column and associated mechanical equipment. Due to the assymmetry of the cross section of the device, large amounts of ballast are required at the opposite side to the water column to ensure that the structure floats at the correct inclination.

The design philosophy used is limit state as embodied in the various codes and recommendations noted in Appendix 'C'. A section is initially designed so that it will not fail at the worst ultimate limit state (ULS). It is then checked to ensure that it complies with various serviceability limit states (SLS), which include deflection, cracking, vibration, corrosion and fatigue.

For the underwater sections, the cracking SLS is the most onerous, with the requirement that cracks may neither be wider than 0.3mm, nor extend

Description of Structure and Philosophy of Design contd.

through the entire section. In areas adjacent to the water column, the fatigue SLS becomes more important because it is expected that up to 3 x 10^8 stress cycles may occur in the 50 year design period.

The underwater sections of the structure are subject to a varying hydrostatic pressure which for the purpose of analysis, may be split into two components. The first is the steady value appropriate to the depth of the section under consideration when the structure is floating in still water. The second is the variable component due to wave action. The design calculations carried out for this stage of the study allowed for the dynamic nature of the wave action by multiplying the wave height by 1½.

Sections adjacent to and above the static water line will be subjected to breaking wave loads. Very little information is presently available upon the magnitude or application of these loads. Accordingly, the design calculations can not fully take these into account, and it is recognised that they may be more severe than the loadings presently used.

Vertical hogging and sagging loads due to waves of the same length as the structure have been assessed and their effects superimposed upon the stresses found for the local hydrostatic and dynamic loadings. The mooring forces cause similar stresses in the horizontal plane.

Description of the Structure and Philosophy of Design contd.

In the region of the base and lower external walls, the variable portion of the loading is fairly small in comparison with the steady component. It was found that reinforced concrete sections were adequate to satisfy the cracking SLS without requiring prestressing. Due to the severity of the cracking SLS it was also found that these sections had very high reserves of ultimate strength.

For sections nearer the water line, the wave action component of the loading predominates and, allied to the necessity to keep weight to a minimum, prestressing is required to ensure that the cracking SLS (which is more severe in the splash zone) is fully satisfied. The rear external wall of the structure has been designed using reinforced concrete supplemented by partial prestressing.

Due to the effects of breaking waves and wave slam, prestressed sections will be used in the water column nose and front wall of the structure. This will allow some measure of precasting.

To speed up construction once the structure is afloat, precast prestressed planks similar to sections presently commercially available have been selected for the water column cover slab, for decking out the machinery spaces and for forming the exhaust ducts. The planks covering the water column are carried on two transverse precast prestressed concrete beams which are propped near their centre. All these planks will be prestressed transversely in a similar way to cellular concrete bridges in order to distribute the effects of

Description of the Structure and Philosophy of Design contd.

breaking or overtopping waves.

Structural Design Specification (Concrete)

The detailed Structural Design Specification is given in Appendix 'C'. The basic design code for concrete sections is BS CP 110 - 'The Structural Use of Concrete'. This is supplemented by other documents which vary the provisions of CP 110 to take account of the more difficult conditions experienced in the marine environment. Structural steelwork required for the reference design has been designed to BS 449 - 'The Use of Structural Steel in Building'.

The limit state philosophy used for the concrete design work requires the determination of various service loads under different environmental and operating conditions. Ultimate loads are then derived from service loads, multiplied by partial safety factors which are determined according to the reliability of the calculations for the values of the loading forces. The ultimate strengths of the materials used are also modified by a partial safety factor appropriate to the quality obtainable under site conditions.

Cracking has been found to be the most onerous of the serviceability limit states. Crack widths have been limited to small values in splash zones because of the corrosive nature of the environment. Elimination of cracking across the complete section is necessary in submerged zones to ensure that the structure remains watertight.

Until recently it has been considered that concrete is not

Structural Design Specification (Concrete) contd.

susceptible to fatigue failure because of the low stresses to which it is subjected. However, in view of the corrosive environment and the expected high number of stress cycles, a fatigue limit state in the form of a permissible stress has been given. This is in line with current good practice. For reinforcement the stress range is considered more important when fatigue is being considered. A suitable maximum value has been given which is applicable for any minimum stress level.

Experience of structures already installed in the North Sea has shown that shear reinforcement must be evenly spread throughout the structure. A maximum spacing of 400mm has been given for any size or type of shear reinforcement.

For normally reinforced sections, a concrete strength of $40N/mm^2$ gives adequate durability. With the more sophisticated crack width calculation methods, which have been developed recently, it has been found that high strength reinforcement may be used.

The precast prestressed sections require a concrete strength of at least $50N/mm^2$ in order to shorten the time at which transfer of prestress may be made.

In general, Grade 43 steel will be used for structural steelwork sections. Fatigue is considered to be a major problem and will be analysed using the cumulative damage method. For preliminary design work, the damage limit ratios have been translated into an additional safety factor which will be superimposed on the safety factors already embodied in BS 449.

Structural Design Specification (Concrete) contd.

Environmental data has been taken initially from the Department of Energy Guidance Notes for Offshore Installations. However, a much fuller analysis based on data available from South Uist and OWS India is being carried out.

Sequence of Construction
Concrete Body

The dimensions and the construction sequence for the concrete structure have been based on the premise that existing shipyard or oil platform construction facilities will be used, (Drg. No. 3).

1. Prepare floor of dock to give a flat rigid construction area of at least 120m x 40m. The area directly under the structure (116m x 35m) is covered with a separating layer to facilitate float-off of structure. This layer must also prevent loss of cement grout from under-surface of base slab.

2. Place high tensile steel reinforcement for base slab and starter walls, erect edge shuttering and place concrete in base to full depth of 0.8m using $40 N/mm^2$ strength concrete.

3. Erect reinforcement and shuttering for outer walls and main longitudinal wall using fixed shuttering to 3-4m in height. Place concrete

Sequence of Construction contd.

in these starter walls and erect slip form shuttering after stripping fixed shuttering.

4. Slipform all external walls to height of approximately 15m, except for front wall at water column entrance, which terminates at 12m.

5. Erect reinforcement and fixed shuttering to all other internal starter walls.

6. Complete all interior walls to 12m level using fixed shuttering and construct slab at 12m level.

7. Remove all construction equipment from dock, clean area and ballast down concrete structure to ensure no float-off until after dock fully flooded.

8. Flood dock by syphon or pumping, check that water has penetrated under all parts of base of concrete structure and deballast structure (draft 8.3m, under keel clearance 1m minimum).

9. Open dock gate or complete removal of bund and tow out to sheltered deep water construction site, moor, and connect up shore communications and access.

10. Commence erection of steel bulkheads to close off face of water columns (strutted off inner wall and erected progressively as concrete construction proceeds).

11. Restart slipforming of external walls and continue

Sequence of Construction contd.

until full height is reached.

12. Construct internal walls using fixed shuttering. Precast 'nose' sections, roof beams and 'planks' on-shore.

13. Clear shuttering and place precast nose sections which are then stressed and grouted.

14. Place roof beams and 'planks' and fix in position.

15. Place ballast concrete in lower cells and add trimming water ballast as necessary.

16. Install machinery and equipment.

17. Construct 'conning tower'.

18. Complete roofs, access and escape hatches.

19. Trim finally with ballast water and prepare for tow to operating site.

    (Note: bulkheads remain in position over water column entrances until after tow to site.)

Construction Programme

A bar chart programme for the construction of concrete units has been prepared (Drg. No. 4).

Construction Programme contd.

This shows that after an initial construction period of approximately nineteen months, one unit per annum can be produced from a single construction site. Certain sites can provide facilities for construction of up to six units concurrently. Assuming construction begins early in the year, the units are ready for installation in August/September of the following year when favourable weather might be expected to allow connection to moorings. Such a construction schedule would minimise the time units would be delayed due to bad weather at installation time and allow additional units to be commissioned prior to winter peak demands for power.

(b) <u>Steel</u>
<u>Description of Structure and Principal Dimensions</u>

The layout configuration of the unit (121.5m x 35m x 33m high) is as shown on the Outline General Arrangement (Drg. No. 5). Each unit consists of a bank of six modules, i.e.,

5 modules	20.0 metres long
1 module	21.5 metres long.

Each module is subdivided into 7 tanks, a machinery compartment and a duct space. Shelter type accommodation spaces are arranged in two of the modules and a storage space is arranged in one of the other modules.

Description of Structure and Principal Dimensions contd.

The accommodation shelter space and storage space are situated on an intermediate flat. There is an inter-connecting passageway at this level between all modules. An arrangement of watertight doors results in each module being a separate watertight compartment. Two access/observation towers are arranged topsides providing main access to the compartments below. It is intended that one of these observation towers could be used as a control post when maintenance operations are in progress. These towers provide sheltered observation facilities particularly in adverse weather.

An allowance of 1,000 tonnes has been made for power generating equipment, towing and mooring fittings and other agreed fittings which will be on board to allow the unit to perform its operational duty.

A provisional lightweight of 13,000 tonnes has been estimated including the 1,000 tonnes of equipment on board referred to above. The floating steelweight is estimated to be about 12,000 tonnes, but could vary by $\pm$ 12½%.

To arrive at this steelweight, a preliminary investigation into possible scantlings has been carried out. In determining scantlings, consideration was given to the operating draft, the location and sea state during operation, the resultant motions, and the fact that the unit would be in service for long periods before drydocking.

Description of Structure and Principal Dimensions contd.

These indicated a fairly robust marine vehicle.

Because of these considerations, in the preliminary scantling evaluation, Lloyds rules for tanker construction were used where appropriate.

It should be noted that the Wave Energy unit, built in steel, will be launched on its side, ballasted upright before mooring at its sea station, and will be eventually deballasted to the original launch configuration for drydocking.

These uprighting or semi-overturning operations will demand structural strength capability. All these factors would at this early stage justify the tanker rule approach.

The unit will be constructed in mild steel to the specification and approval of the appointed Classification Agency (Drg. No. 6).

The type of construction adopted will be as follows: The unit will be longitudinally framed, the longitudinal members supported by transverses spaced about 4 metres apart.

Transverse bulkheads will be arranged with vertical stiffeners supported by horizontal stringers. In way of the water column area, double skin tranverse bulkheads will be stiffened vertically, the stiffeners being supported by horizontal diaphragms.

Description of Structure and Principal Dimensions contd.

All steel intended for fabrication will be flame heat dried, shotblasted to S.A. 2½ standard, prime coated with a selected epoxy based fabrication primer and oven dried. An external coating system of chlorinated rubber and anti-fouling is proposed along with pitch epoxy coatings for the internal water ballast tanks.

Impressed current and sacrificial anode systems have been considered. After discussions with suppliers, a sacrificial anode system is proposed.

Sequence of Construction

Within Lithgow's fabrication shed facilities, the wave energy units will be constructed in prefabricated sections of up to 85 tonnes in weight. These sections will be joined together into assembly units of up to 225 tonnes in weight. To suit the necessary launching requirements, the wave energy unit will be erected on the building berth as shown on Drawing No. 7, all in accordance with a sequence of building control, using the 225T Goliath crane. It is the intention to install all equipment necessary for the operational role of the wave energy unit, prior to launch, and this will be part of the sequence of building methods adopted. Equipment installed will include all piping necessary for the ballasting and deballasting operations.

Preliminary launching evaluations for Lithgow's facility only using launch weight ranging from 12,000/14,000 tonnes and

Sequence of Construction contd.

allowing for water over way ends of about 2.8 metres, have been carried out.

To achieve this order of water over way ends at Lithgow Limited's Glen Yard, an extension to the existing launching prongs will be necessary. Results show that this extension may require to be increased due to bow dip occurring in the chosen launch condition.

After launching, the wave energy unit will be towed to the Scott Lithgow outfitting quay and moored (Drg. No. 8). Preparation for the follow-on uprighting ballasting operation will be carried out at this location. The unit will then be towed down the river channel and on to the ballasting location (Drg. No. 9). The unit will be moored, then ballasted down using a barge or support vessel suitably equipped with pumping and control equipment.

The ballasted unit will be towed to the operating site.

Construction Programme

It is anticipated that in the production of a series of wave energy units, the following reduction in direct labour man-hours can be achieved:

(a) Fabrication shed manhours

Unit 1	-	100% manhours
Unit 2	-	95% manhours of unit 1
Unit 3	-	90% manhours of unit 1
Unit 4 and subsequent	-	85% manhours of unit 1

Construction Programme contd.

(b) Building shed manhours

Unit 1	-	100% manhours
Unit 2	-	95% manhours of unit 1
Unit 3 and subsequent	-	90% manhours of unit 1

(c) Other shipyard trades

Unit 1	-	100% manhours
Unit 2 and subsequent	-	95% manhours of unit 1

(d) Direct staff costs

Unit 1	-	100% manhours
Unit 2 and subsequent	-	30% manhours of unit 1.

Material costs and labour rates will vary in accordance with appropriate indices for the respective timescale for construction of subsequent units. (Drg. No. 11)

CHAPTER 3 - ONBOARD EQUIPMENT

The NEL Oscillating Water Column device consists of two systems, the Primary Conversion System which is the oscillating water column itself, and its housing which forms part of the structure (described in Chapters 1 and 2); and the Secondary Conversion System which is all the plant used to convert the wave energy in the water column into electrical power.

The Secondary Conversion System

The Secondary System consists of four banks of rectifying valves and one air turbine directly coupled to an electric alternator, for each of the six air columns, plus all ancillary equipment necessary to support power production. The rectifying valves are analagous to a four valve electrical rectifier and convert the oscillating air flow in the column into a pulsating, but unidirectional, supply to the turbine.

In designing the system, the emphasis was placed on high efficiency at the cost of some increased complexity. High reliability can nevertheless be achieved by good engineering design and sound operational practices.

Performance and other design calculations pertaining to the system are given in Appendix 'D'.

Model test experience in the narrow tank at NEL indicates that the column motions of correctly damped free-floating devices are always controlled, even in extreme conditions, and never threaten to flood the turbine completely. However, no doubt some water will enter the ducting and as a preliminary

The Secondary Conversion System contd.

investigation into this problem, a ducting similar to that of this reference design was tested in the Edinburgh tank at 1/150 scale. Some results of these tests are given in Appendix 'D'. These indicate that the quantities of water entering the ducting will not prove an over-riding problem.

Rectifying Valves

Drawing No. 12 shows an outline design of the valves of which there are four banks per column as shown in the General Arrangement. Detailed design of the valves has still to be undertaken.

The valves are hydraulically actuated and form a cascade when open which assists the flow around the bends in which they are situated. The actuators are signalled by the pressure difference across the valves. The requirement is for a high strength to weight ratio, corrosion resistant material and GRP (medium quality) has been selected. The valves rotate about a point close to their centres of gravity thus minimising the actuation torque. When closed, the leading and trailing edges are sealed by a compliant element kept under compression by the actuators. Leakage around the sides is controlled by maintaining a clearance of not more than 2.0mm. The rotary actuators will be powered by a hydraulic accumulator through a control valve, the accumulator being kept charged by two electrically driven hydraulic pumps, each capable of maintaining the pressure should the other fail. Each column has its own hydraulic package.

Air Turbine

A radial inflow turbine has been selected because machines of this type have high efficiencies and a head-flow characteristic approaching the linear ideal. Variable inlet guide vanes (VIGV's) which are used to enhance the cycle efficiency automatically adjust to suit the instantaneous flow rate, as signalled by a pressure differential in the pneumatic circuit. There is an over-riding control imposed upon their operation by a rev/min signal and in this way the VIGV's are also used to prevent overspeed.

The mechanical design of the turbine has not been undertaken. It is, however, envisaged that the ducting, the VIGV's and runner would be made from GRP. The design speed and head of this machine are modest by current standards so that stress levels in the runner will be low. Gyroscopic loads should not cause any difficulty.

The following data applies:

Design Head	207m of air
Design Flow	$75m^3/s$
Design Power (output)	173kW
Design Speeds	377 rev/min
Runner Diameter	2.66m
Estimated Runner Weight	2700kg
Estimated Runner Radius of Gyration	1.15m
Estimated Inertia Constant	16 s

A very preliminary study by International Research and Development Limited of the effect of different inertia constants on system performance indicated that there is an optimum value of around 15 secs (refer to TAG 6 paper 'A Preliminary Investigation into the Turbine Characteristic and Flywheel

Air Turbine contd.

Requirement for use with the NEL Oscillating Water Column' by J R Bumby, 12 May 1978). In view of these findings, no additional rotating inertia (flywheel) has been provided.

Alternator

The Power Station is designed to give a maximum continuous input to the National Grid of 100MW. Assuming this to be divided equally between the 150 alternators, it gives approximately 850kW per machine, allowing for losses. This is the mean about which the instantaneous output will fluctuate in extreme conditions. Peaks up to perhaps 3MW need to be tolerated in order to achieve this mean. The alternator is controlled locally by an AVR system with over-riding current and temperature limit feedback and backup fuses.

Specification

Screen protected, drip-proof, salient pole, brushless alternator.

MCR	1.5MW at 500 rev/min
Overspeed	800 rev/min
Supply	6.6kW 3ph.

The estimated weight is 20,000kg.

Other Onboard Equipment

All necessary control and monitoring equipment is duplicated on board and all routine lubrication is fed automatically.

Other Onboard Equipment contd.

Bilge and drainage pumps are powered electrically and operate as required from onboard indication. Reserve batteries power standby equipment in the event of a mains failure.

Navigation and warning lights are displayed on the 'conning tower'.

The following list covers the main items of equipment:

Secondary system isolation valve (permits maintenance of secondary system)	6 off
Column control (bypass) valve (allows column damping to be maintained when isolation valves are closed)	6 off
Overhead gantry cranes	6 off
Generator cooling system	6 off
Main switches	6 off
Ballast handling pumps and valves	
Bilge pumps	
Turbine duct drain pumps	
Auxiliary supply transformers	
Auxiliary supply batteries	
Lubrication systems	
Condition monitoring equipment	
Mooring load monitors	
Navigation lights	

CHAPTER 4 - TRANSMISSION SYSTEM

The recommendations contained in TAG 6 paper - 'Proposal for the Electrical Transmission by hV - DC from Wave Energy Converter to Shore' by J D Ainsworth, 26 September 1977 have been adopted.

The outputs from each of the six alternators onboard each floating unit are transmitted by separate flexible cables to separate diode rectifiers through isolation (step-down) transformers. The six transformers and rectifiers, together with the necessary switchgear, are housed in a single module situated on the seabed. All the 150 rectifiers of the power station are connected in series and supply the national grid through a single, shored-based, inverter and control station. A feature of this arrangement is that there is no requirement for a communication link to co-ordinate rectifier, alternator and inverter control - the alternator and rectifier being controlled locally. Monitoring and over-riding control cables are, however, provided.

The proposal for the power export cable comprises six flexible cables together with the control cables contained in a GRP sprung helical tube. These cables, the tube and the seabed module would be installed on the seabed as one sub-assembly. Subsea connections would be made using a diving bell. The flexible cables would be connected up to the floating unit as shown in Drg. No. 13.

CHAPTER 5 - MOORINGS

A tensioned spread mooring is seen at present as the most likely system to satisfy the requirements of the design.

Mooring Design

The moorings are tensioned and consist of twenty four mooring lines to attachment points at two levels on the unit. Drawings Nos.14 and 15 show the layout of the system at rest and in the extreme positions assumed in the calculations.

The attachment points on the concrete structure are at 14 and 18 metres below the water line to allow clearance for ships to come alongside for maintenance and repair of equipment. The steel version of the unit would have mooring points situated in similar locations. The mooring lines are made up of approximately 30m of wire rope at the top end for hook up, 124m of eight plait nylon rope in the middle section for elasticity, and approximately 10m of wire rope at the bottom end for attachment to the deadweight concrete block, or anchoring point and to prevent abrasion of the nylon rope on the seabed.

The type of anchors will be determined by the seabed conditions and since the units will be spread out over a large area, different seabed conditions will be encountered. In the absence of a full site investigation, it has been assumed that the seabed is sandy and flat.

Since the mooring system is tensioned, there are large uplift forces. A combined system of concrete deadweights to resist the uplift forces and drag anchors to resist horizontal forces has been selected.

Mooring Design contd.

The eight plait nylon rope was selected for its particular characteristics:

(a) high strength and energy absorption capacity;
(b) high resistance to cyclic loading and abrasion;
(c) highest extension of all the fibre ropes;
(d) flexibility and resistance to kinking.

These characteristics are necessary to the tensioned system to obtain as short a scope as possible.

Basis of Design (See Appendix 'E')

1. Maximum horizontal force exerted on the unit by the mooring - 24MN.

2. Maximum horizontal excursion of $\pm$ 30m from pretension position.

3. Maximum vertical excursion of $\pm$ 16.5m from pretension position.

4. Nominal water depth - 80m.

5. Two rows of attachment points are provided at depths of 14m and 18m.

6. Maximum load capacity of each attachment point - 15MN.

7. Safety factor on attachment points of 4 giving maximum working load of 3.75MN.

Basis of Design contd.

8. Safety factor on mooring line load of 2.5

9. The mooring lines are never allowed to lose tension.

10. All lines are of the same length for practical reasons of availability and storage of spares etc.

11. The lines consist of three sections:

    30m of wire to allow hook up

    124m nylon to provide elasticity

    10m of wire to protect nylon from abrasion at the seabed.

CHAPTER 6 - INSTALLATION:

The floating units will be moored in a single line running north-south, with an interval of approximately 3½ unit lengths between each unit. A single line is the array which gives the optimum abstraction of energy from the approaching wave fronts for the capital invested.

Site Preparation

Prior to the installation of a unit's mooring system, a comprehensive survey of seabed and soil conditions will be carried out and a suitable anchoring system selected. The location will be marked by a survey vessel using modern and accurate methods of fixing position at sea. The site for each unit will be marked by an array of marker buoys and acoustic transponders positioned so that the location at which each anchor has to be laid can be readily determined.

Anchor Installation

The anchor in the proposed mooring system comprises of two parts - a fluke anchor (Bruce type) and a concrete deadweight - the fluke anchor to resist horizontal forces and the deadweight the vertical forces. Installation will comprise of first laying the fluke anchor and a length of chain from an anchor handling supply vessel fitted with position fixing equipment. The anchor will then be 'dug-in' in the desired direction. With the aid of a second vessel, a proof load will be applied to the anchor to approximately 2.0MN (two thirds of the ultimate design load).

Anchor installation contd.

The final position of the anchor will be computed and charted. The end of the chain will be marked by a buoy attached to a pennant wire. This operation will be repeated for all 24 fluke anchors.

The deadweight will be installed from a crane barge, which will lower the deadweight using the pennant wire as guidance. The deadweight will have a temporary acoustic transponder fitted to ensure accurate positioning. The final locking-on of the deadweight to the chain will be carried out by divers operating a chain stopper.

Rode Installation

The combined mooring rode made up of man-made and wire rope, will be attached to the deadweight anchor using a socket installed on the anchor. The surface end of the rode will be supported in a finger buoy to facilitate final connection to the unit.

All mooring rodes will be installed in this manner, and buoyed at the surface prior to the arrival of the unit.

Connecting Up

Each mooring point on the unit, prior to leaving the fitting out location, will have a steel mooring cable attached with the free end made fast to the deck.

The unit, under tow by four tugs, will be positioned in the centre of the array of buoyed moorings.

Connecting Up contd.

The connections will be made using a mooring barge having two winches each with a heaving capacity of 1.5 MN. Starting at the weather side at one corner No. 24 (See Drg. No. 14), the mooring barge will moor alongside the unit and with the assistance of a tug, connect the winch wire to the pick-up buoy of the prelaid mooring. The buoy will then be winched towards the unit, and the connection between the wire and the man-made rope will be made using a conventional shackle. A similar procedure will be followed at the opposite corner No. 9. The operation is then repeated for Nos. 12 and 21. The unit is now on station, having one mooring attached at each corner, and the tugs can be released. The remaining connections are then made in the following sequence, 3, 4, 5, 6, 15, 16, 17, 18, 12, 22, 23, 11, 1, 2, 7, 8, 13, 14, 19, and 20.

A concrete structure has the water head on each side of the bulkhead gates balanced and the gates removed by crane and divers, and is then trimmed with ballast to its operating mode. The gates will be returned to construction site for further use and ultimately retained for future maintenance work.

The same operations would be carried out for a steel structure although it is likely it would be towed out already ballasted and with the water columns open.

<u>Connection to System</u>

Supply and control cables which have all been previously laid on the seabed and buoyed off, are picked up and winched aboard the floating units. The connections are made in the special terminal compartments which are isolated from

Connection to System contd.

the rest of the structure to prevent ingress of water.

CHAPTER 7 - OPERATION AND MAINTENANCE:

Operation

The alternative of manned or unmanned units has been considered. Because of the continuous motion of the structure in the sea, the comparatively low freeboard of the structure, the need to minimise openings in the structure, the possible difficulty in changing crews for long periods in winter time, the large number of men required, and the costs in providing acceptable long term living accommodation on board each unit, it has been decided the reference design units should be unmanned. These would be remotely controlled from the shore station.

On the concrete structures, three accesses for personnel have been provided. The principal access is by way of a 'conning tower' at one end of the structure. This contains a 'lock' type of entrance which, by using watertight doors at each end of a chamber, prevents water ingress to the structure. Escape hatches backed by 'lock' chambers are located at the middle and at the end of the structure remote from the 'conning tower'. On the steel structure, two 'conning towers' are provided for access, one at each end.

When units are 'on-load' their operation is controlled by the system demand. Over-riding control and monitoring from the shore station is provided by a subsea control cable, backed up by a secondary radio-link. This would enable units to be taken out of service as required.

Maintenance

The concrete structure has been designed for an expected fifty year life. It is not anticipated that it will suffer significant damage except perhaps due to collision with a ship or another OWC structure breaking moorings.

Should repair or maintenance prove necessary the water column area could be completely de-watered by refitting the construction bulkheads. For access to the exterior of the rest of the structure, it would require to be released from its moorings and towed to a sheltered inshore anchorage for repair to be effected.

The steel structure would be drydocked at approximately ten year intervals. For this deballasting and tilting into its original launching configuration is necessary.

It is expected that the main burden of maintenance and repair will be in the mechanical and electrical fields. As the device consists of a large number of identical units, the provision of spares and replacements at some central point is the most economical arrangement. A central supply base equipped with berthing facilities for maintenance ships and the infrastructure to service them would be set up (Drg. No. 10).

To cover the spread of units, a large 'mother ship' would be required. This would house maintenance and repair crews, main workshops, stores and all repair facilities.

This ship would be attended by two or more repair tenders which would ferry men and materials to and from the floating units.

Maintenance contd.

It is not intended that any workshop or living accommodation be permanently on board the units. The first items to be landed at the start of a visit would be a 'survival' package containing liferaft, radio, first-aid kit, food, bedding, fuel and emergency generator. This would be followed by a 'maintenance' pack of basic workshop gear, lubricants and spares.

Apart from routine maintenance or replenishment of lubricants, it is not intended that any repair work other than of a minor nature will be carried out on board the structure. Planned maintenance or repair will be by replacement of components and to this end, suitable access hatches and lifting beams have been provided. Exchange of heavy components would be by crane from the 'tender' moored alongside the unit.

Maintenance crews will not live on board units under repair. They will be replaced at the end of each shift by another crew from the mother ship. The only use of the 'survival' pack will be in the event of heavy weather preventing the crew being taken off.

Maintenance and Inspection of Moorings

The maintenance and inspection procedures are preliminary since there are likely to be stipulations laid down by the insurance underwriters and the certifying authorities. Based on current practice, the following is envisaged:

Annually:
Each complete mooring cable will be inspected visually using remote controlled TV cameras.

Maintenance and Inspection of Moorings contd.

It is likely that the cables will require to be scrubbed at least in part, to remove marine fouling prior to visual inspection. This could also be carried out remotely from the surface. Detailed inspection of certain areas will be carried out by divers as directed by the certifying authority. Components requiring replacement will be removed by first relieving the tension using the mooring barge and diver support, then by recovering the complete cable system by releasing at the deadweight. The renewal will be a repeat of the initial installation.

Every Five Years:
The fluke anchor and chain will require to be recovered for inspection at the surface. This will be carried out by first relieving the tension as before, disconnecting the chain from the chain stopper at the deadweight, then recovering the fluke anchor and chain by vertical pullout. The deadweight will not be disturbed. The fluke anchor will be relaid by dropping and digging in as before. The chain will be laid across the deadweight. Divers aided by mechanical equipment will reposition chain and 'lock in' the stopper.

It is expected that an individual mooring system will have a life in excess of 10 years, although replacement of minor components may be necessary within this period. Experience with the system will generate design improvements, and it is not expected that more than 25 per cent of system replacement

Maintenance and Inspection of Moorings contd.

will be necessary in any 10 year period.

Mooring Monitoring

A force monitoring system will be used for determining the condition of the mooring and the loading experienced during its life.

The monitoring system will be incorporated in the unit attachment points, using strain gauges and a central readout and recording system mounted on board each module. This system will be fitted with alarms for overload or failure of an individual mooring line and will record the number of load cycles which have been experienced. This information, backed by comprehensive knowledge of fatigue behaviour of the components, will provide a further safeguard against cyclic failure.

Electrical and Control Cables

The main electrical power cables and control cables will also require replacement from time to time due to flexing and abrasion. These will be lowered away from the structure to the seabed and a prelaid replacement winched into place.

APPENDIX 'A'

LIST OF DRAWINGS AND FIGURES:

APPENDIX 'A'

List of Drawings and Figures contd.

APPENDIX 'B'

PRIMARY EFFICIENCY:

Measurements of primary efficiency, i.e., conversion of wave into air power, have been made in monochromatic waves and mixed seas. Tests have been conducted at 1/150, 1/100, and 1/50th of full scale, with the results showing a good consistency throughout. Efficiencies of the steel reference design and concrete reference design for small monochromatic waves are shown in Fig. 1. The sea efficiencies of Figs 2 and 3 are for the steel design only. However, it is reasonable to apply the monochromatic behaviour of the concrete design to the patterns obtained. The reduced peak efficiency is to some extent compensated by a superior performance at lower frequencies.

The sea efficiencies in Fig. 2 have been obtained directly by measurement, and also by applying the monochromatic performance for small waves to the Pierson-Moskovitz spectrum, assuming efficiency to be independent of wave steepness. The direct measurements were made covering the OWS 'India' scatter diagram, using a 21 component Pierson-Moskovitz spectrum of long-crested waves. The model was a 1/150th scale version of a prototype having a characteristic column length of 12m and a total width of 120m. The points plotted are for the 'India' envelope.

Fig. 3 gives some indication of the change in device efficiency with incident wave angle and device width. Generally it would appear that the wider the device, the better the performance. The reference design is the same width as the 10 section model used in these tests. Long-crested waves were used and the particular spectrum with which the tests were conducted was not the Pierson-Moskovitz but a mixed sea roughly comprising the components used in previous monochromatic work. The sea efficiency has been calculated for the incoming power contained in a wave front of length equal to the model width, independent of wave incidence.

The data on the effect of wave direction applies to a single device in a wide tank and cannot be applied directly to a long line of devices as proposed in the reference design. It is not knownby how much directional effects reduce the amount of energy extracted by such an array. This is a major area of uncertainty but some allowance must be made. In the calculations of Appendix 'D' a factor of 0.5 has been applied, which is based on estimates made by Rendel Palmer and Tritton.

APPENDIX 'C'

NEL OSCILLATING WATER COLUMN

STRUCTURAL DESIGN SPECIFICATION

1. Design Codes and Recommendations:

   1.1 General
   1.2 Concrete Structure
   1.3 Steel Sub Structures

2. Loads:

   2.1 Dead Loads
   2.2 Imposed Loads
   2.3 Environmental Loads
   2.4 Deformation Loads
   2.5 Loading Conditions
   2.6 Loading Cases
   2.7 Loading Combination

3. Design of Concrete Sections:

   3.1 Design Approach
   3.2 Limit States
   3.3 Ultimate Limit State
   3.4 Serviceability Limit States
   3.5 Design and Detailing
   3.6 Materials

4. Design of Steel Subsections:

   4.1 Materials
   4.2 Permissible Stresses
   4.3 Fatigue Limit State

APPENDIX 'C'

Structural Design Specification contd.

5. Environmental Data:

5.1 General Information
5.2 Winds
5.3 Waves
5.4 Currents
5.5 Temperatures
5.6 Marine Growth

P20/ Air turbine : est. runner weight = 2700 Kg (GRP)

P21/ Alternators : 150 per 100 MW scheme

850 KW per machine

20,000 Kg / alternator.

P23/ Transmission : from device

6 (?) helical GRP cables per device - 0.5m diameter.

P24/ Moorings : 24 lines : each have 30m + 10m wire rope and

124m of 8 plait nylon rope.

P32/ "The concrete structure has been designed for an expected

fifty year life"

"The steel structure would be drydocked at approximately

ten year intervals"

P33-34/ Maintenance and inspection

ANNUALLY : Mooring cables (requires scrubbing

5-YEARLY : Fluke anchor & chain

"It is expected that an individual mooring system will

have a life in excess of 10 years"

"... it is not expected that more than 25 per cent of

system replacement will be necessary in any 10 year period"

App D/ Output data.

	DEVICE CAPTURE	DIRECTIONALITY	POWER CHAIN	RELIABILITY	RESULTING LOAD FACTOR
Appendix D	·25?	·50	(·94x·95x·96x·95x·80)=·65	·90?	= ·07
RPT 1978	·39	·65	·30	·87	= ·07

(for further details see Page 65)

App E / Mooring node data –

Nylon ropes: 124m long × 250mm diameter

Wire ropes: (30m long + 10m long) × 115mm diameter

Deadweight: 10m × 10m × 10m concrete blocks.

Drag-in anchors: 9,000Kg Bruce anchors.

Aside: Energy input to mooring

Nylon = 6·09 m^3 × 1,150 Kg/m^3 × 200 MJ/Kg = 1400 GJ/node

Wire = ~~1·22 m^3~~

0.42 m^3 × 7,860 Kg/m^3 × 43 MJ/Kg = 142 GJ/node

Concrete deadweight = 100~~0~~ m^3 × 3400 MJ/m^3 = 340~~0~~ GJ/node

Drag anchors = 9000 Kg × 44·000 MJ/Kg = 396 GJ/node

TOTAL = ~~5338~~ 2278 GJ/node

24 nodes/unit; 25 units/100 MW.

i.e. 2GW scheme => 12000 nodes => ~~64~~ 27 × 10^6 GJ/2GW.

(Cf input based on RPT 1978 system: 77 × 10^6 GJ/2GW).

NEL-OWC 2ND INTERIM REFERENCE DESIGN July 1978

P1/ 100 MW Power Station: 25 units, each containing 6 OWC's.

P2/ 35m wide, 25m draft. CONCRETE REFERENCE DESIGN.

Water column cross-section: 12m x 18m

Unit dimensions: 116m long x 35m wide x 30-35m high.

STEEL REFERENCE DESIGN

121.5m long x 35m wide x 33m high.

P3/ Spacing: 400m between structures

540m spacing of centres.

total length: 100MW, 25 units = 13.5 Km.

P12/ Construction - CONCRETE DESIGN

Period = 19 months.

1 unit per annum from single construction site.

(Certain sites could provide 6 units concurrently)

P13/ STEEL DESIGN

Allowance of 1,000 tonnes for power generating equipment, towing + mooring fittings, and other agreed fittings.

Floating steel weight ~ 12,000 tonnes ± 12½% ?

P15/ Mild steel construction - flame heat dried, shotblasted, prime coated with epoxy based primer & oven dried.

External coating - chlorinated rubber, antifouling with pitch epoxy coating for internal water ballast tanks.

- Sacrificial anode system used.

Construction data - uses 225 tonne Goliath crane.

APPENDIX 'C'

1. DESIGN CODES AND RECOMMENDATIONS:

1.1 General. The wave energy device will be designed in accordance with the following Codes and Recommendations:

Department of Energy - Offshore Installations, Guidance on Design and Construction, 2nd Edition;

Lloyds Register of Shipping - Rules and Regulations for the Classification of Wave Energy Devices (not yet published).

Reference may also be made to:

Lloyds Register of Shipping - Rules and Regulations for the Classification of Ships;

Lloyds Register of Shipping - Rules for the Construction and Classification of Mobile Offshore Units, 1972.

1.2 Concrete Structures. Concrete sections will normally be designed using the limit state approach as embodied in the following Codes and Recommendations:

British Standards Institution - CP 110: Part 1 1972 - The Structural Use of Concrete;

F.I.P. - Recommendations for the Design and Construction of Concrete Sea Structures, 3rd Edition.

Lloyds Register of Shipping - Rules and Regulations for the Classification of Offshore Installations. Fixed Concrete Installations, draft edition, February 1978.

APPENDIX 'C'

Design Codes and Recommendations contd.

1.3 Steel Sub Structures. Where steel sections are used in conjunction with a mainly concrete structure, their design will be carried out using the permissible stress approach as embodied in the following Code:

British Standards Institution - BS 449: Part 2: 1969 - The Use of Structural Steel in Building.

Note: The above permissible stress design approach may eventually be replaced with a limit state approach when revisions to BS 449, presently under draft, are published.

2. LOADS:

Loading on the structure will be considered from the following causes:

2.1 Dead Loads (Gk)

(a) Weight in air of structure and superstructure;

(b) Equipment not normally moveable;

(c) Ballast, wet or dry;

(d) Stored liquids;

(e) Hydrostatic external pressure and buoyancy in calm sea conditions calculated for still water design draft.

2.2 Imposed Loads (Qk)

(a) Mooring and towing forces;

(b) Moveable equipment;

Loads contd.

2.2 (c) Personnel;

(d) Maintenance crane loading;

(e) Ships or other vessels during mooring or while moored;

(f) Helicopters landing, taking off, or while parked on the structure.

2.3 Environmental Loads (Vk)

(a) Waves, including effects of slam, slap and breaking. Hydrodynamic effects should also be included;

(b) Air pressures in the water column;

(c) Currents;

(d) Wind;

(e) Icing.

2.4 Deformation Loads (Dk)

(a) Prestress;

(b) Shrinkage and expansion;

(c) Creep;

(d) Temperature variation.

2.5 Loading Conditions

Values of loads will be calculated under the following environmental conditions:

(a) Normal environmental conditions, having a return period of one month;

Loads contd.

2.5 (b) Extreme environmental conditions, having a statistical return period of 100 years.

2.6 Loading Cases

Values of loads will also be calculated for the following service conditions:

(a) Construction and installation;

(b) Normal operation;

(c) Turbine shut down condition (controlled conditions);

(d) Air column control valve failure condition;

(e) Damage stability.

2.7 Loading Combinations

The following loading combinations will be checked:

(1) Normal environmental conditions for the construction and installation load case. Maximum imposed loads will be taken where appropriate;

(2) Normal environmental conditions for the normal operation load case with maximum imposed loads;

(3) Extreme environmental conditions for the turbine shut down condition. Imposed loads will be assessed and relevant maximum values included;

Loads contd.

(4) Extreme environmental conditions for the air column control valve failure condition. Imposed loads will be assessed and relevant maximum values included;

(5) Extreme environmental conditions for the damage stability load case. Imposed loads will be assessed and relevant maximum values included.

3. DESIGN OF CONCRETE SECTIONS:

3.1 The normal approach will be to design to satisfy the ultimate limit state and then to check that the serviceability limit states are not reached. In a number of cases a serviceability limit state may be more critical.

3.2 Limit States

(1) Ultimate;

(2) Serviceability:

(a) Deflection
(b) Cracking
(c) Vibration
(d) Corrosion
(e) Fatigue

APPENDIX 'C'

Design of Concrete Sections contd.

3.3 Ultimate Limit State

3.3.1 Partial Load Factors (γ f)

Load Condition		Loading Combination				
		1	2	3	4	5
Dead & hydrostatic	Gk	1.2*	1.2	1.1	1.05	1.05
Imposed	Qk	1.6	1.6	1.3	1.05	1.05
Environmental	Vk	1.4	1.4	1.3	1.05	1.05
Deformation	Dk	1.1	1.1	1.1	1.05	1.05

*During construction or installation if the structure is subjected to short term loads of a hydrostatic or similarly well defined nature γ f may be taken as 1.05.

3.3.2 Partial Material Factors (γ m)

	Strength Assessment	Excessive load or local damage
Concrete	1.5	1.3
Steel	1.15	1.0

3.4 Serviceability Limit States

3.4.1 Partial Load Factors (γ f)

For all load conditions and combinations

γ f = 1.0

APPENDIX 'C'

Design of Concrete Sections contd.

3.4 3.4.2 Partial Material Factors (γm)

	Deflection	Cracking Fatigue
Concrete	1.0	1.3
Steel	1.0	1.0

3.4.3 Deflection. Adjacent to installed plant deflection may have to be limited to ensure satisfactory operation of equipment and valves.

3.4.4 Cracking. The following limitations on crack widths and stresses will apply:

(a) Classification

Reinforced Concrete:

Cracking Classification	Crack width (mm)	Stress limit in reinforcement
A	0.1	
B	0.3	
C		0.67 fy

Prestressed Concrete:

Cracking Classification	Criteria
1	No tension
2	No visible cracks
3	Crack width 0.1mm

APPENDIX 'C'

Design of Concrete Sections contd.

3.4.4

(b) Cracking Classification and Section Location

Zone	Environmental Condition	Reinforced Concrete	Prestressed Concrete
Submerged	Normal	B	2
	Extreme	C	3
Splash	Normal	A	1
	Extreme	B	2
Atmospheric	Normal	B	2
	Extreme	C	3

For short term well defined loading during construction and installation -

	Reinforced Concrete	Prestressed Concrete
All zones	C	3

(c) In the submerged zones cracking across the full section will be completely eliminated by providing a compression zone not less than 30% of the effective depth of the section, nor less than 200mm..

(d) Crack widths will be estimated using the method given in CP 110 Appendix A3. With a cyclic loading the stiffening effects of the concrete in the tension zone will not be taken into account when the fluctuating portion of the load exceeds 75% of the steady portion.

3.4.5 Fatigue

Due to the predominantly cyclic nature of the loading, in particular adjacent to the air column, fatigue analysis will be carried out. The design life for concrete sections will be taken as 50 years.

For preliminary design in areas adjacent to the air column, the following fatigue stress limits will apply at serviceability limit states:

Concrete - normal environmental
Maximum compressive stress in direct compression or bending limited to a maximum value of 0.33 fcu.

Reinforcement - normal environmental
The stress range in straight deformed high tensile reinforcement will be limited to 100 N/mm^2 when imposed on a minimum stress level up to 0.4 fy.

3.5 Design and Detailing

3.5.1 Ultimate Limit State

(a) Shear and torsion resistance.
The provisions of Appendix 1 of Lloyds Register of Shipping Rules and Regulations for the Classification of Offshore Installations, Fixed Concrete Installations will apply.

APPENDIX 'C'

Design of Concrete Sections contd.

3.6 Materials

3.6.1 Concrete

	Grade 40	Grade 50
Characteristic strength	40	50 N/mm^2
Age factors - 6 months	1.18	1.15
12 months	1.25	1.02
Modulus of elasticity	31	34 kN/mm^2

3.6.2 Reinforcement Steel

High yield deformed bars to BS 449

Characteristic strength 410 N/mm^2

Modulus of elasticity 200 kN/mm^2

3.6.3 Prestressing Steel

Type to be selected

Modulus of elasticity 200 kN/mm^2

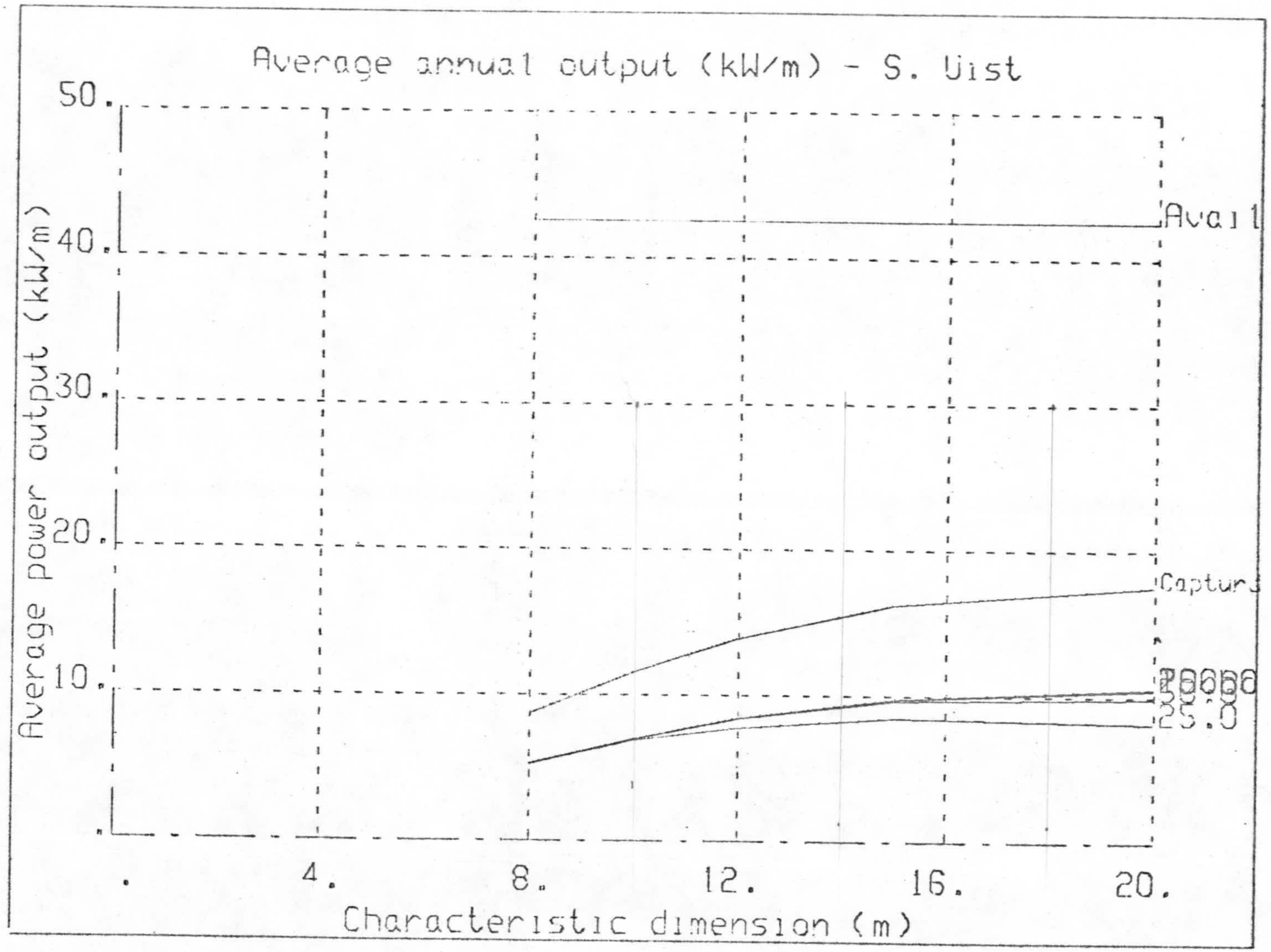
4. DESIGN OF STEEL SUBSECTIONS:

4.1 Materials

In general, structural steels which comply with BS 4360 will be used.

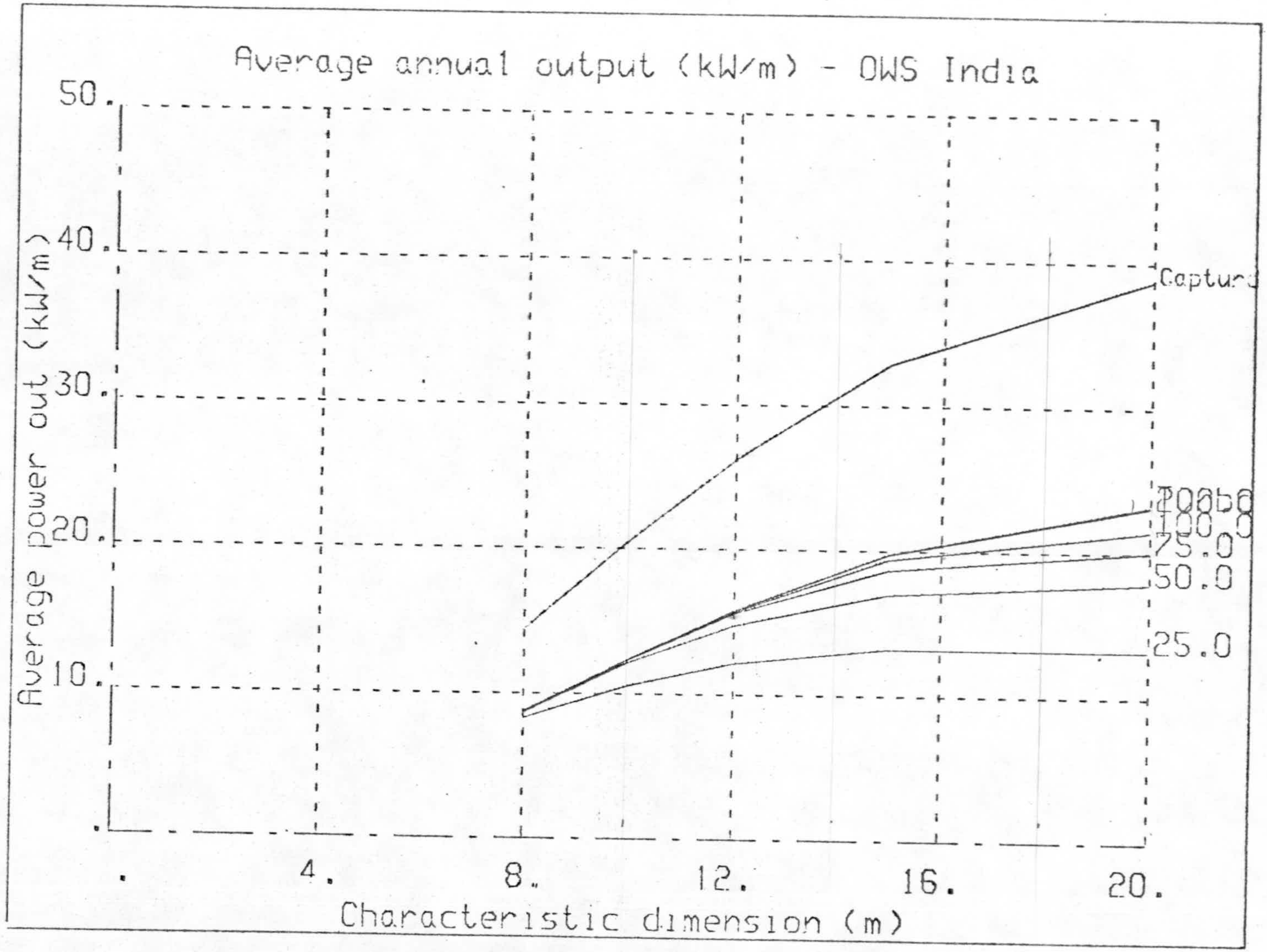
For structural members the following Charpy impact values and minimum grades of steel will apply:

NEL 81



89.5 mm = 40 kW/m
= 0.446 (kW/m)/mm

NELA2


Average annual output (kW/m) - OWS India
Average power out (kW/m)
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40.
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Characteristic dimension (m)
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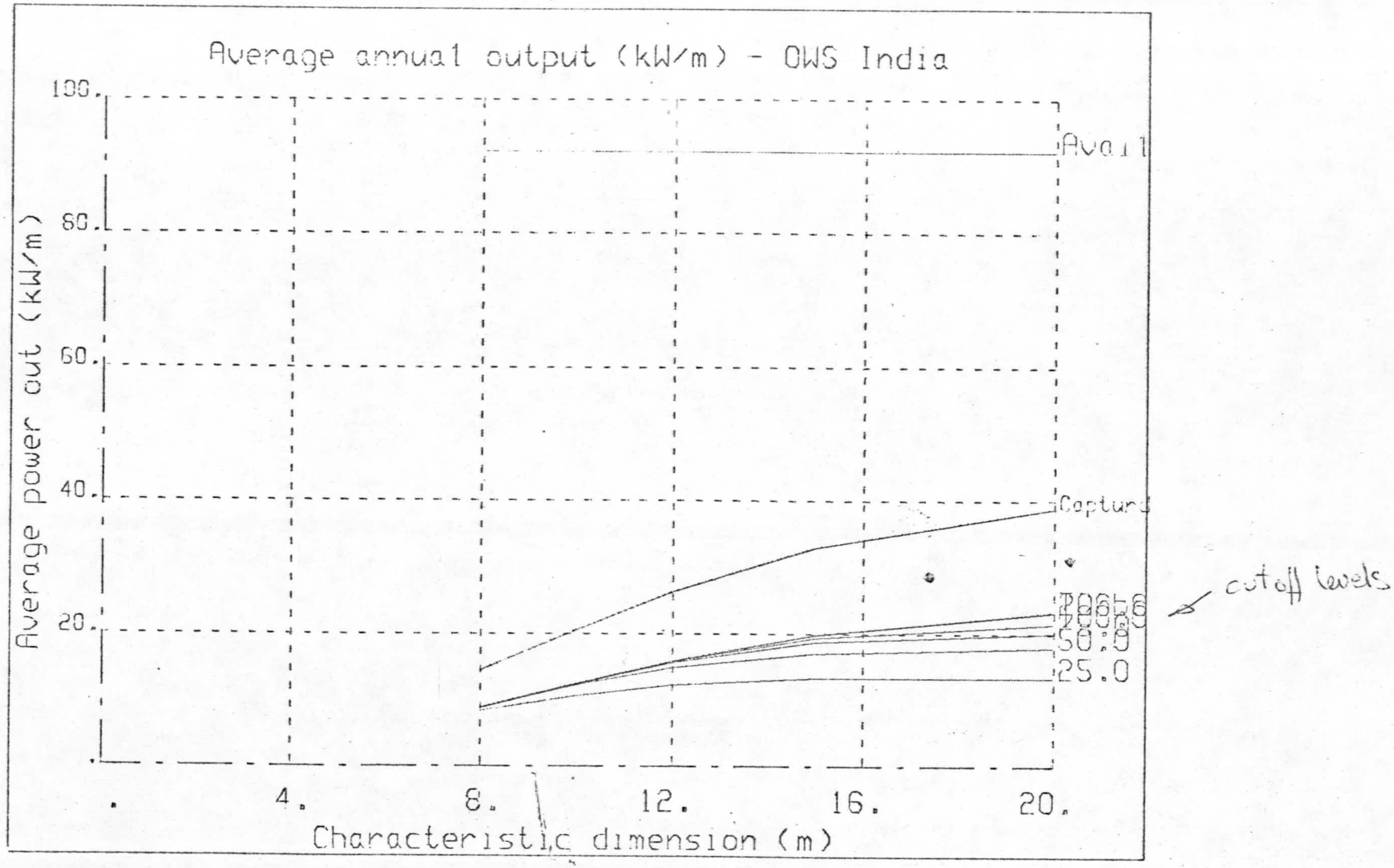
50.0
25.0

NEL A1


Average annual output (kW/m) - OWS India
Average power out (kW/m)
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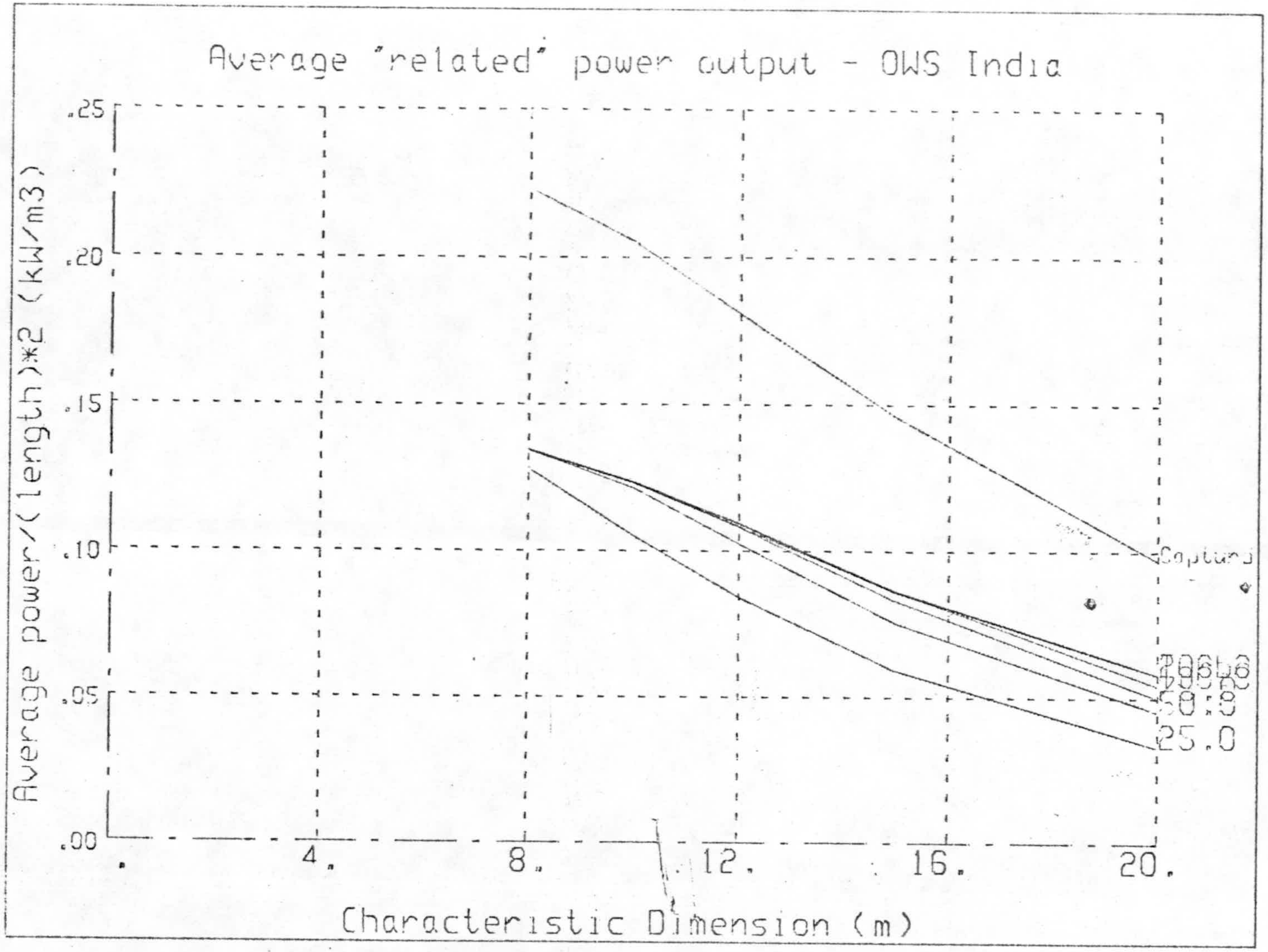
Average 'related' power output - OWS India
Average power/(length)*2 (kW/m3)
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Characteristic Dimension (m)
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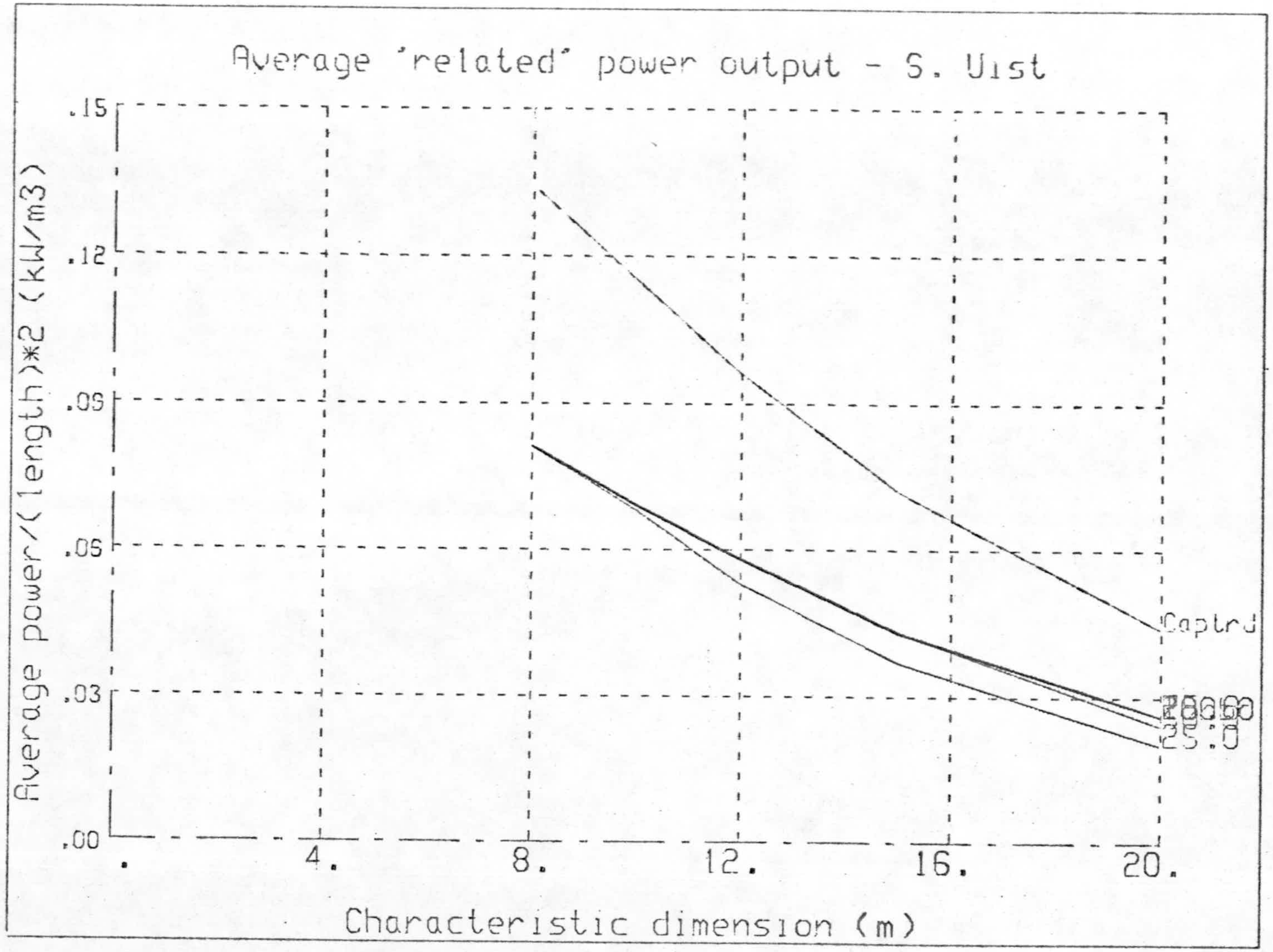
Average 'related' power output - S. Uist
Average power/(length)*2 (kW/m3)
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Characteristic dimension (m)
Captrd

Design of Steel Subsections contd.

	Exposed Locations		Non-Exposed Locations	
	Charpy Impact Value	Minimum Grade of Steel	Charpy Impact Value	Minimum Grade of Steel
Plate	27J @ $-10^{o}C$	43D	27J @ $0^{o}C$	43C
Sections	27J @ $-10^{o}C$	43D	27J @ $0^{o}C$	43C
Hollow Sections	27J @ $-10^{o}C$	43D	27J @ $0^{o}C$	43C

4.2 Permissible Stresses

The following overall limitations to permissible stresses will apply:

	Maximum Permissible Stress
Normal environmental	0.6 fy
Extreme environmental	0.8 fy

4.3 Fatigue Limit State

In view of the predominantly cyclic nature of the loadings, a full fatigue analysis will be carried out using the cumulative damage method, i.e., Miner's rule -

$$\sum_{i=1}^{s} \frac{ni}{Ni} \leqslant \eta$$

APPENDIX 'C'

Design of Steel Subsections contd.

where ni = number of cycles occurring in stress range i

Ni = number of cycles in stress range i needed to cause failure

s = number of stress ranges considered (which must be not less than 10)

and η = damage limit ratio

values of η shall be taken as follows:

	Accessibility		
	No access	Access	
Importance of structural member	location all zones	location in and below splash zone	location above splash zone
Major	0.1	0.3	1.0
Minor	0.3	1.0	1.0

To take account of fatigue in preliminary design calculations the permissible stresses given in BS 449 will be further reduced by use of an additional safety factor as follows:

i.e. Design permissible stress = $\dfrac{\text{Permissible stress from BS 449}}{\gamma m}$

Values of γ m

APPENDIX 'C'

Design of Steel Subsections contd.

		Accessibility		
		No access	Accessible	
Importance of structural member	Nature of Loading	Location all zones	Location in and below splash zone	Location above splash zone
Major	cyclic	7.0	3.0	1.5
	non-cyclic	3.0	1.5	1.0
Minor	cyclic	4.5	2.0	1.2
	non-cyclic	1.2	1.0	1.0

5. ENVIRONMENTAL DATA:

5.1 General Information

Location	Atlantic Ocean (West of Hebrides)
Water depth	80m
Mean Spring tide range	2 - 3m
Storm surge	1m

5.2 Winds

Wind speeds at 10m above sea level for an average recurrence period of 50 years:

(a) maximum 3 sec gust (m/s) 56

(b) hourly mean speed (m/s) 40

APPENDIX 'C'

Environmental Data contd.

5.3 Waves

	Normal Environmental once per month	Extreme Environmental return period 100 years
(a) Height (Crest to trough)	20.0m	37.0m
(b) Maximum Period	11 sec	17-19 sec

5.4 Currents (Mean Spring tides)

(a) at surface (m/s)	0.9	1.0
(b) at seabed (m/s)	0.5	0.4

5.5 Temperatures

(a) air temperature range (^{o}C) 5.0 to 13.0

(b) sea temperature range (^{o}C) 7.5 to 11.5

5.6 Marine Growth

To be agreed.

APPENDIX 'D'

ONBOARD EQUIPMENT CALCULATIONS:

Results of Water Ingress Tests on a Model Ducting

The tests were carried out at 1/150 scale in the Edinburgh wave tank using long-crested, mixed frequency waves with P-M spectra. There was a great deal of scatter in the results from run to run. The worst were obtained from the biggest sea-state and are given below (scaled up).

Energy period T_e = 14 s

Root mean square surface elevation y_{rms} = 4m

Duration = 42 minutes

	Total quantity of water which entered the ducts (m^3)	
	From column	From outside
Run 1	47	145
Run 2	18	3
Run 3	13	18

(The power required to raise $145m^3$ of water through a head of 12m in 42 minutes is approximately 7kW.)

For y_{rms} less than and equal to 2m no ingress was observed.

APPENDIX 'D'

RECTIFIER:

The rectifying system has two functions in that flow is not only turned on or off, but also guided. There are four banks of vanes per chamber, operating in pairs so that a unidirectional flow through the turbine is produced. To keep flow losses to an acceptable level, the area of the valve housing is large ($\simeq 16m^2$) and a practical section minimising free board is 3.2 x 5m. The vane shape and number have been chosen using the information collated by Idel'chik. A reasonable compromise between losses incurred through leakage, actuation and flow resistance is obtained with six vanes. A large number of vanes is preferred for reduced inertia and hence lower actuating powers.

The vanes are supported on a steel grid, the central members of which are solid spars of elliptic section. The major diameter is 0.35m and the aspect ratio is 5. Hollow spars would be lighter but bigger. The frame and vanes are designed to take a maximum differential pressure of $10^5 N/m^2$. The high aspect ratio ensures that area blockage is small ($\simeq$ 5.5 per cent). Four spars are sufficient to keep the vane length to an acceptable value in terms of low stress and low intertia.

The guide vanes, of which there are 30 per valve bank, are constructed from GRP because of its favourable strength to weight ratio.

The vanes will be flange-coupled to bearings located in each spar. The maximum static load per bearing is about 55kN, the dynamic loads being small. Thrust bearings will be required for positive location rather than for any large

APPENDIX 'D'

Rectifier contd.

load carrying capacity.

The total inertia which must be actuated is estimated to be $80 kg/m^2$ per valve bank.

The valves operate over a fixed rotation of 55° at regular intervals, typically 10 seconds. The required operating period is about 0.5 secs, and occurs at each zero crossing of pressure. The actuation system is taken to be non-conservative in that all input energy is dissipated. A residual torque is applied during rest periods to assist valve sealing. An estimate of actuator rating and power losses has been made assuming a sinusoidal velocity distribution.

The following estimates have been made in relation to actuation of one valve bank:

Required torque	=	0.8kN-m
Peak power	=	2.5kW
Energy used	=	1.5kJ

The last figure refers to electrical input to the hydraulic actuator package and assumes a mean system efficiency of 25 per cent. It is equivalent to a mean power requirement of about 1.3kW per column based on a 10 sec cycle.

APPENDIX 'D'

TURBINE SIZING:

The chosen turbine is an inward flowing radial machine of the Francis type. It has been chosen for its near linear head-flow characteristic passing nearly through zero head and flow. The peak efficiency is 94 per cent, and the flow rate band is extended by the use of variable inlet guide vanes. The characteristic can be made very linear by suitable guide vane manipulation, thereby matching the preferred column damping. The turbine is characterised by its specific speed and specific diameter, respectively.

$$N_S = \frac{\omega_o Q_o^{1/2}}{(gH_o)^{3/4}} = 1.132$$

and
$$D_S = \frac{(gH)^{1/4} D}{Q^{1/2}} = 2.06$$

where ω_o = design speed (rad/s), H_o = design head (m), Q_o = design flow (m^3/s) and D = runner diameter (m).

Given linear damping of the column, H = KQ, the following relationships may be easily derived

$$\omega_o = N_S (gK)^{3/4} Q_o^{1/4}$$

$$D = D_S (gK)^{-1/4} Q_o^{1/4}$$

Both speed and size are determined once a design flow is chosen. The optimum value of K derived from model data is 2.76 s/m^2.

DESIGN FLOW:

The preferred flow rate by which the turbine size and speed

APPENDIX 'D'

Design Flow contd.

are calculated is obtained by optimising the efficiency of the turbine with the annual distribution of power obtained after primary conversion for a particular sea. The mean turbine efficiency in a particular sea state may be obtained from the steady state characteristic using the relationship

$$\bar{\eta}_t = \int_0^{\infty} \frac{\eta(Q)\ \phi(Q)\ Q^2\ dQ}{Q^2_{rms}}$$

where $\phi(Q)$ is the distribution of flow rate in that sea state. A normal distribution has been assumed (refer WESC (GT16.76)).

The steady state and mean efficiency curves for a normal distribution are shown in Fig. 4.

It is necessary to apply the mean efficiency data to the distribution of Q_{rms} values throughout the year. This has been done using the South Uist data, ignoring directional effects, taking K = 2.76 s/m^2 and applying the calculated sea efficiency given in Fig. 2. By examining the resulting distribution in relation to the mean efficiency data, it was estimated that the optimum design flow for the turbine would be 105 m^3/s and that its mean annual efficiency would be 0.71. Making an allowance for directional effects (remembering that power is proportional to Q^2) has led to the selection of 75 m^3/s as the actual design flow.

This gives:

Design head $\quad H_o = 207$m

APPENDIX 'D'

Design Flow contd.

Design Flow	Q_o	=	$75m^3/s$
Design Power	P_o	=	173kW
Design Speeds	n_o	=	377rev/min
Runner Diameter	D	=	2.66m

GYROSCOPIC FORCES ON TURBINE BEARINGS:

The gyroscopic moment is given by

moment = inertia x rotational speed x rate of precession

or

$$M = mk^2 \omega \frac{d\phi}{dt}$$

where ϕ = angle of roll.

Taking $\frac{d\phi}{dt}_{max}$ = 0.1 rad/sec

and ω_{max} = 80 rad/sec

gives $M = 2700 \times 1.15^2 \times 80 \times 0.1$Nm

= 29kN-m

The rotor weight is about 27kN so that the gyroscopic loads on a pair of bearings about one metre apart are comparable with the gravitational load. Gyroscopic loads must be considered in the design but do not constitute a special problem.

APPENDIX 'D'

FLOW LOSSES:

The total loss of the secondary system is the sum of the losses of the individual components for a given sea state and velocity probability curve. For any component the instantaneous loss is given by

$$\frac{C \rho A V^3}{2}$$

where C is the loss coefficient

A is a characteristic area; and

V the velocity.

The loss associated with a velocity distribution, ϕ (v) is

$$\int_0^\infty \frac{C \rho A V^3}{2} \phi (v) \, dv.$$

Taking a normal distribution and non-dimensionalising the integral with respect to the average power in the air

$$P_A = \rho g \; Q_{rms} \; H_{rms}$$

a flow efficiency may be obtained. Thus,

$$\eta_f = 1 - \frac{0.284}{Q_{rms}} \sum_o^n C_n \, V^2_{rms}$$

where n is the number of components.

The efficiency may be quoted in a more usable form:

$$\eta_f = 1 - 0.0284 \; Q_{rms} \sum_o^n \frac{C_n}{A_n^{\;2}}$$

APPENDIX 'D'

Flow Losses contd.

From this it can be seen that for reduced losses the characteristic area should be large. Significantly, the efficiency decreases linearly with mean flow rate while the average power increases as the square.

For the system shown in Drg. No. 13, the loss coefficients obtained from Idel'chik's 'Handbook of Hydrodynamic Resistance' and the characteristic areas of the components are given in the table. Substitution in the above expression gives:

$$\eta_f = 1 - 5.1 \times 10^{-4} Q_{rms}.$$

For the design flow rate of $75m^3/s$ this becomes approximately 0.96.

Component		C	A
			m^2
Duct inlet	1	0.56	16.0
1st Valve	2	0.50	16.0
Turbine inlet	3	0.04	5.26
Diffuser outlet	4	1.00	12.0
2nd Valve	5	0.50	16.0
Duct discharge	6	1.00	16.0

The coefficients may be obtained without recourse to precision engineering, though it may prove necessary to use fixed guide vanes in the diffuser and some of the bends.

APPENDIX 'D'

Leakage Losses

Leakage will occur around the sides of the valves and the leakage flow rate can be estimated from

$$Q_L = C_d \; A_L \; \sqrt{2gH}$$

where C_d = discharge coefficient $\simeq 0.6$

and A_L = nominal leakage area.

Each bank of valves will have a total length along the support spars where leakage takes place of 32m. It is assumed that elsewhere leakage is negligible. Except during actuation, two banks of valves will be closed giving a total length of 64m.

Taking H = KQ a volumetric efficiency may be obtained. Thus

$$\eta_{vol} = \frac{C_d \; A_L \; \sqrt{2gK}}{Q}$$

Assuming a normal distribution, a gap of 2mm and $C_d = 0.6$, the mean volumetric efficiency at a sea state is given by

$$\bar{\eta}_{vol} = 1 - \frac{0.45}{\sqrt{Q_{rms}}}$$

APPENDIX 'D'

SYSTEM LOAD FACTOR:

The turbine efficiency, flow efficiency and volumetric efficiency at a sea state has been expressed as a function of Q_{rms} assuming Q to be normally distributed. Applying these relationships to the expected annual distribution of Q_{rms} would give the mean annual output at the turbine shaft but, because our knowledge of directional effects is incomplete, this distribution is not known. The above relationships have therefore been applied to the South Uist data ignoring directional effects and for a turbine with a design flow rate of $105m^3/s$. The result was then divided by two to allow for directional effects, multiplied by 0.95 to allow for alternator and mechanical losses and 20kW per unit were then subtracted to cover supply to the valve actuators and ancillary equipment. This calculation gave an estimated mean annual efficiency output from each unit of 0.45MW. Allowing 0.8 efficiency for transmission and a nominal factor of 0.9 for downtime gives a system load factor of 8 per cent.

The rating of the station has not been optimised. It was set at a level which does not noticeably reduce the annual output. This is not unreasonable in view of the relative cost of rated machinery and the moored structure.

APPENDIX 'E'

MOORING DESIGN

1. Rodes and Anchors

In order to maintain the maximum load on the attachment points below 3.75MN, 24 mooring lines are used as shown in Drg. No. 14.

For the purpose of this reference design, it was considered appropriate to make some simplifying assumptions in order to facilitate calculation, viz:

(a) the mooring is symmetrical;

(b) lines 1-8 and 13-20 are designed using the assumptions of extreme fore and aft motion shown in Drg. No. 15. At position 2, lines 1-8 are at maximum extension and exert a horizontal force of 24MN and at position 3, lines 16 and 17 are at zero extension;

(c) lines 9-12 and 21-24 are designed using corresponding assumptions applied to sideways motion. In this case, a force of 8MN is used;

(d) the deadweight can resist the largest uplift force;

(e) the drag-in anchor can resist the largest horizontal force.

Mooring Design contd.

From the manufacturer's data for type of nylon rope selected, at 40 per cent break load the extension is 55 per cent (Fig. 5). Applying this figure to the above assumptions allows the mooring to be designed.

The data given in Tables 1, 2 and 3 (Figs. 6, 7, 8 and 9) is obtained and specifications below derived.

Nylon ropes:	Length 124m Diameter 250mm Breaking load 8.5MN
Wire ropes:	Lengths 30m and 10m Diameter 115mm Breaking load 8.5MN
Deadweight:	Concrete blocks 10m x 10m x 1m
Drag-in anchors:	9,000kg Bruce anchor, which the maker claims has a holding power of approximately 4MN in sand.

2. Wind and Current Force

The maximum mooring force due to wind and current can be estimated using

$$F = \tfrac{1}{2} C_c \rho_w DLU_c^2 + \tfrac{1}{2} C_w \rho_a BLU_w^2$$

APPENDIX 'E'

Wind and Current Force contd.

where C_c	=	current drag coefficient	=	2 (bluff body)
ρ_w	=	density of water	=	$1{,}000 Kg/m^3$
D	=	draft	=	25m
L	=	length	=	120m
U_c	=	maximum current speed	=	0.5m/s
C_w	=	wind drag coefficient	=	1
ρ_a	=	density of air	=	$1.2 kg/m^3$
B	=	free board	=	12m
U_w	=	maximum wind speed at sea surface	=	50m/s

This gives $F \simeq 3MN$

FOOTNOTE:

The reference design mooring was modelled at 1/150 scale and given some preliminary tests in the Edinburgh wave tank during the last week in June 1978. It was tested in a variety of pseudo random (P-M), long-crested seas with the wave direction head-on to the columns. Winds and current cannot be simulated in the tank. In the most severe conditions (root mean square surface elevation, y_{rms} = 4m and energy period T_e = 14 s) the maximum line extension is 47%. These figures suggest that the loads and excursions used as the basis of design are of the right order, but on the low side. The data has not yet been fully analysed.

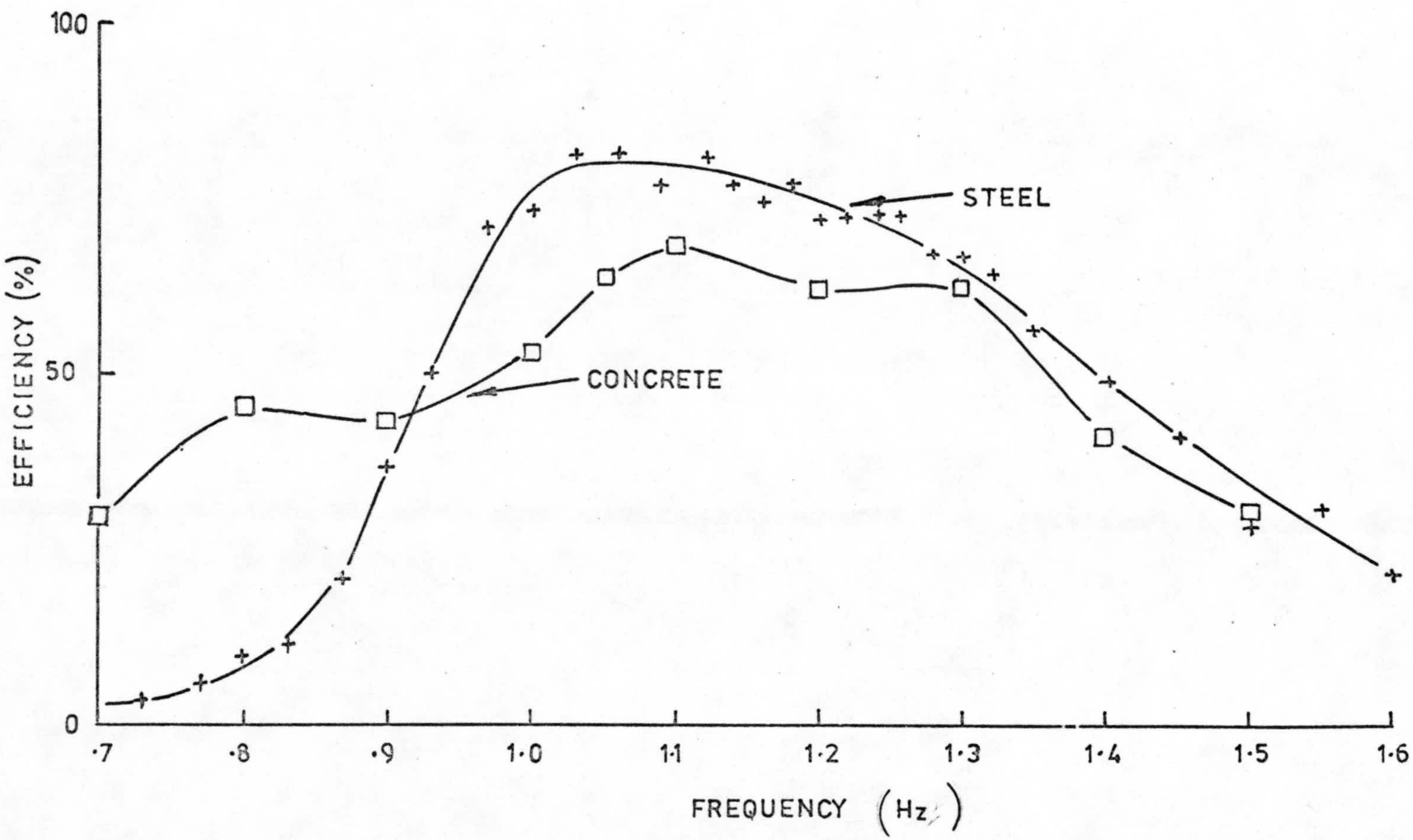


FIG.1 MONOCHROMATIC EFFICIENCY OF THE STEEL & CONCRETE REFERENCE DESIGNS AT $\frac{1}{100}$th SCALE

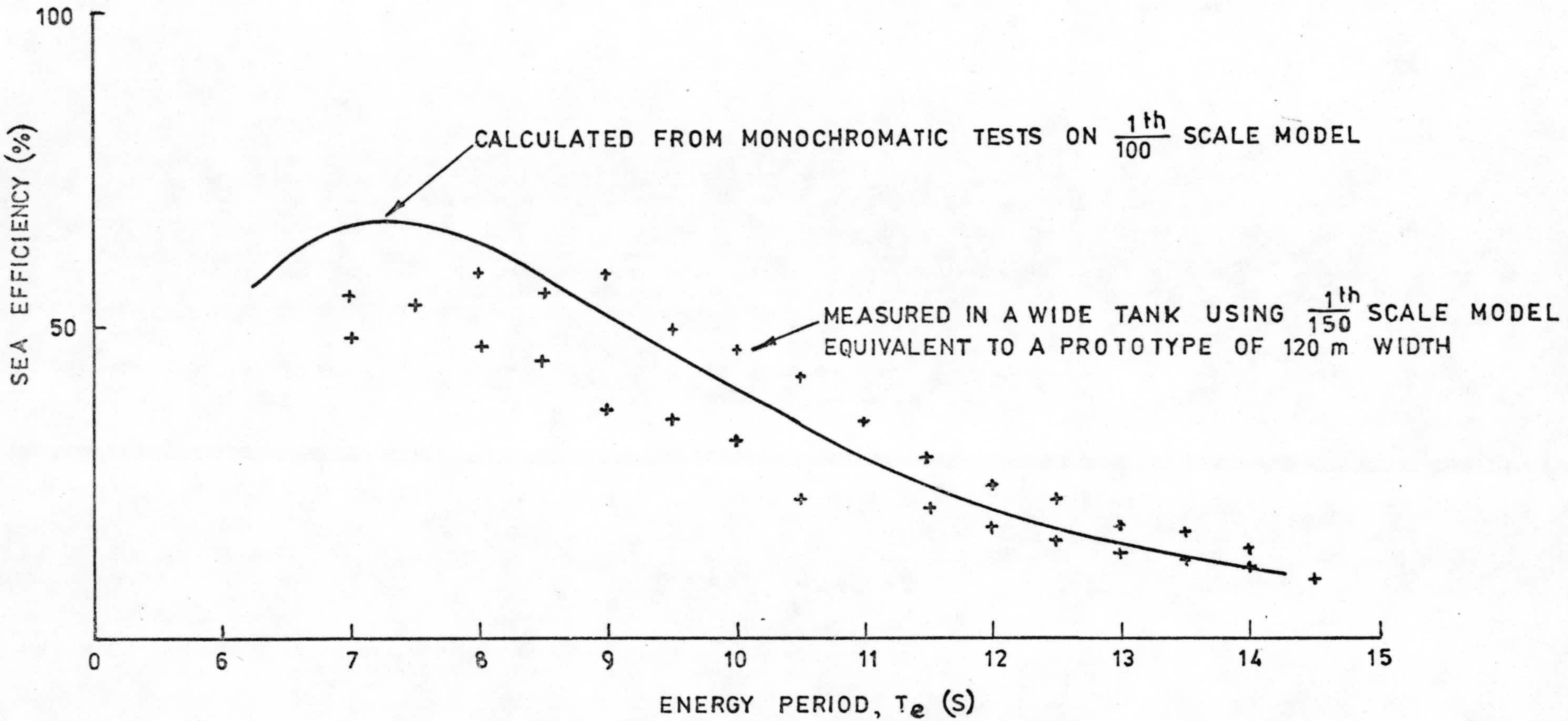


FIG. 2 SEA EFFICIENCIES OF STEEL REFERENCE DESIGN SCALED TO 12m COLUMN FOR P—M SPECTRUM

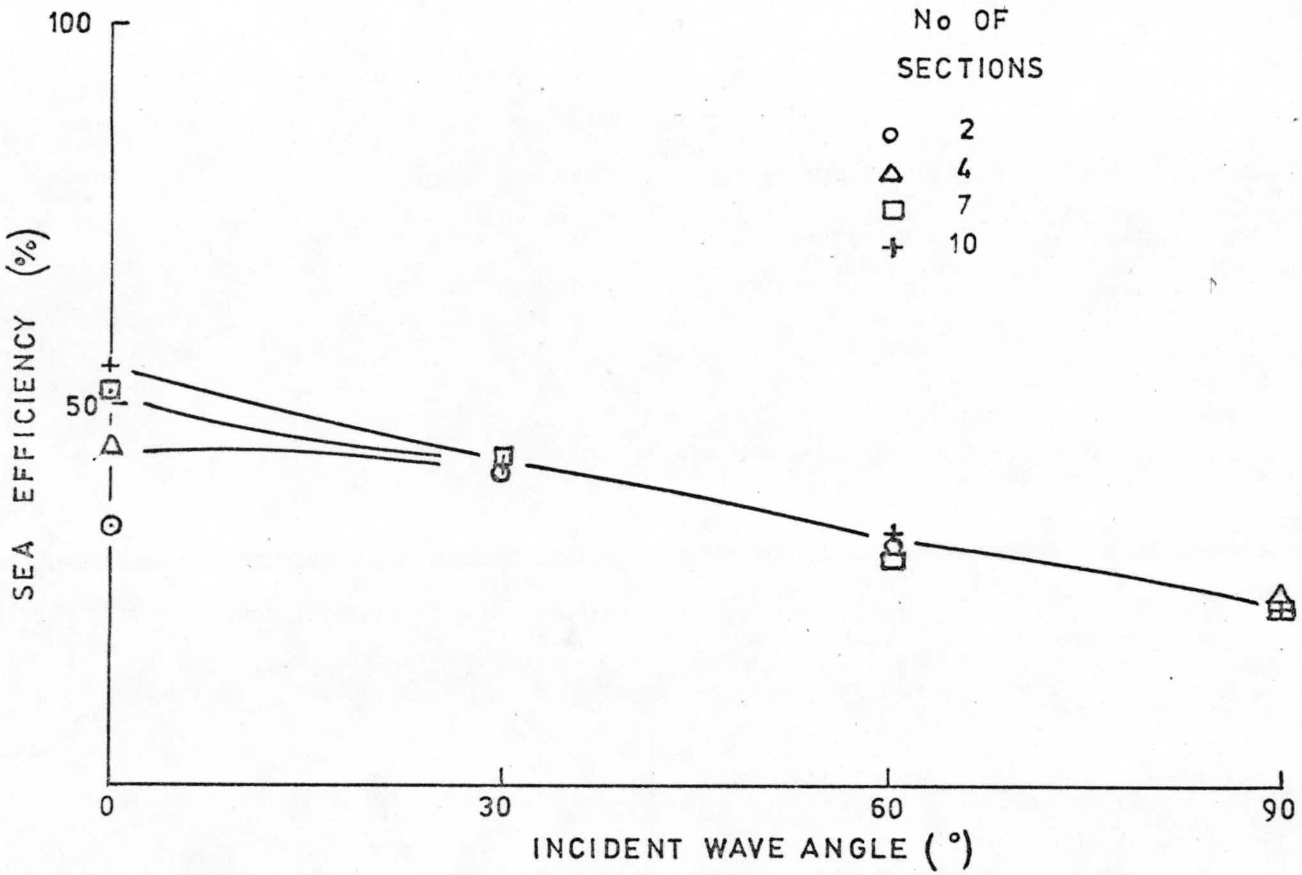


FIG. 3 SEA EFFICIENCY OF STEEL REFERENCE DESIGN AS A FUNCTION OF WAVE ANGLE & MODEL WIDTH

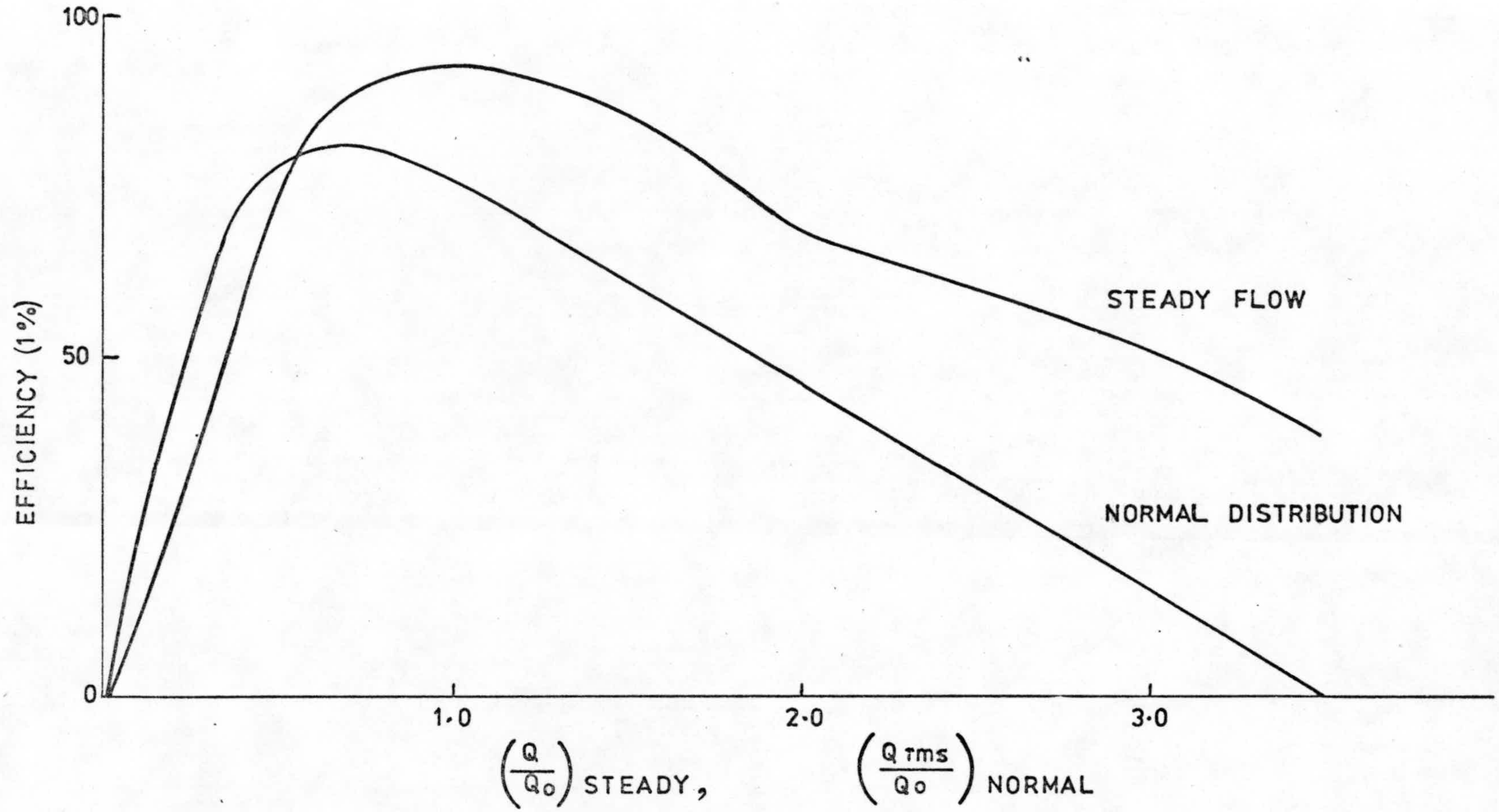


FIG. 4 TURBINE EFFICIENCIES FOR STEADY FLOW AND NORMAL DISTRIBUTORS

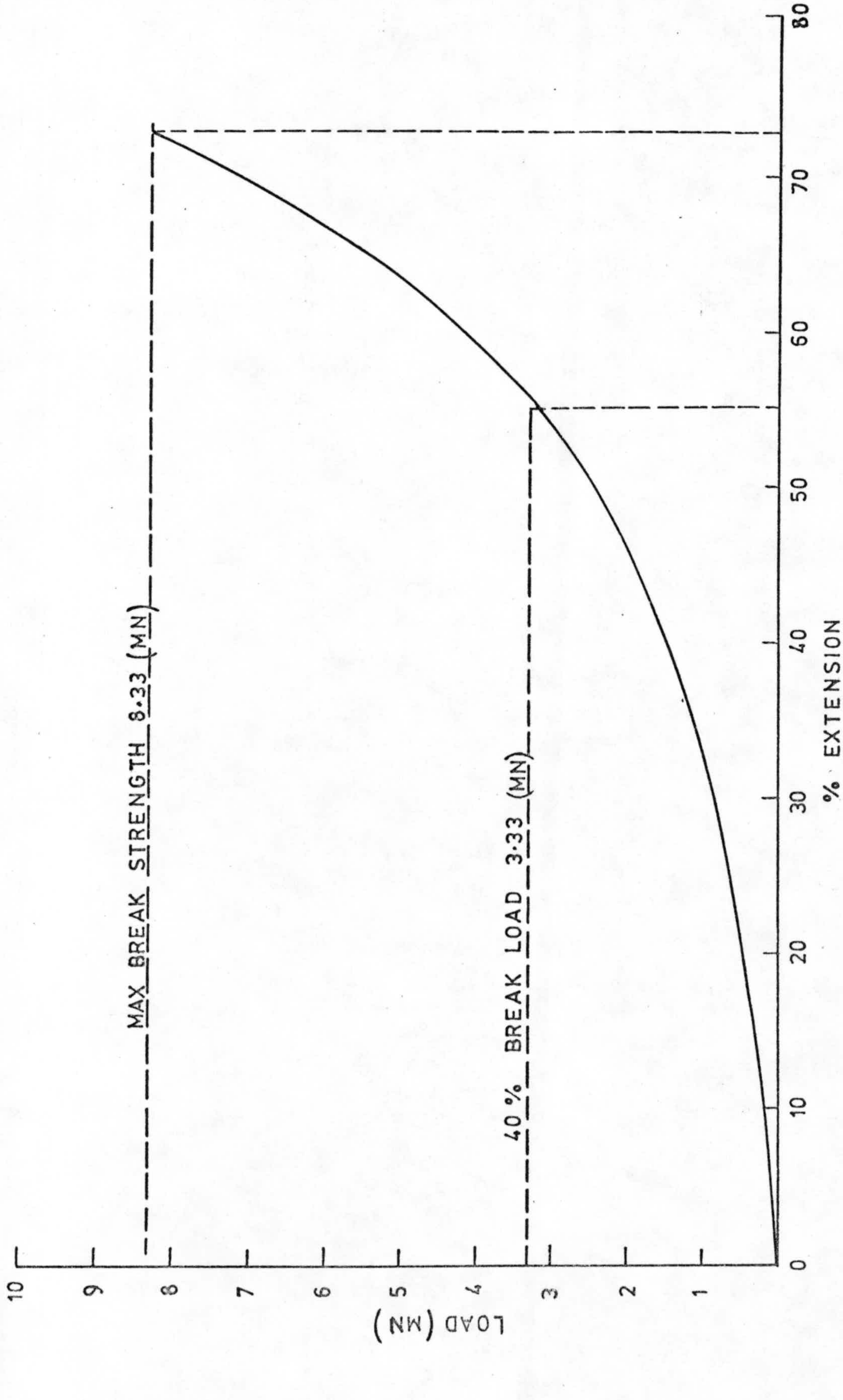


FIG 5 8 STRAND PLAITED NYLON LOAD EXTENSION CHARACTERISTIC

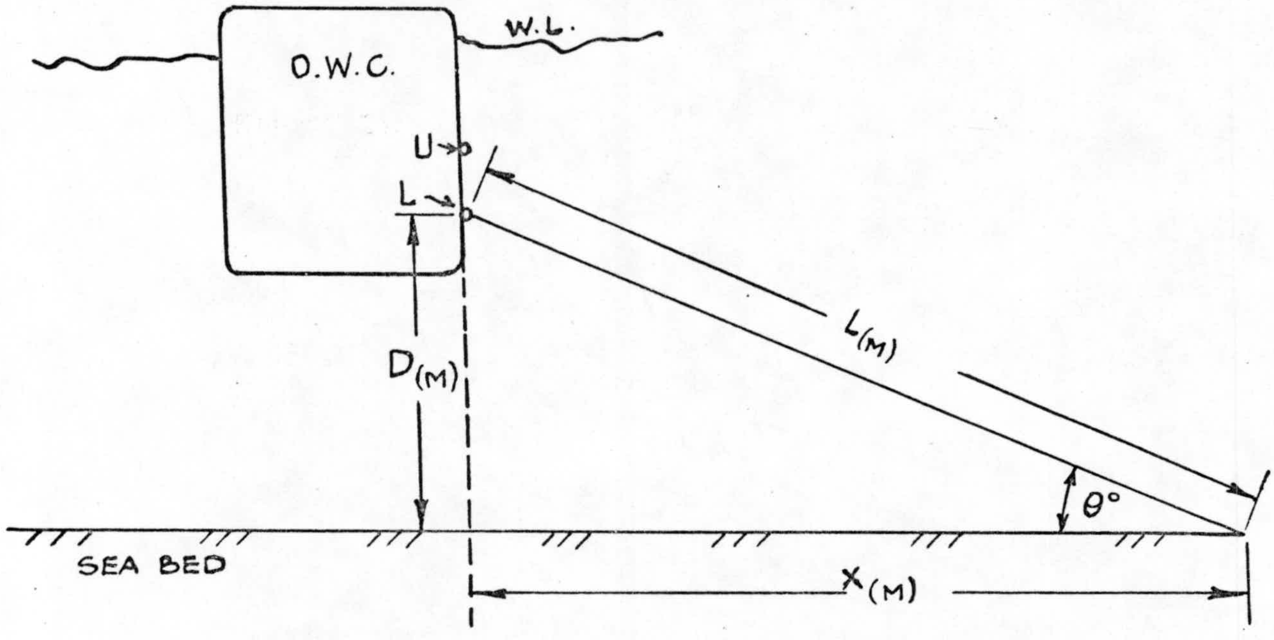


TABLE DIMENSIONS (TRUE)

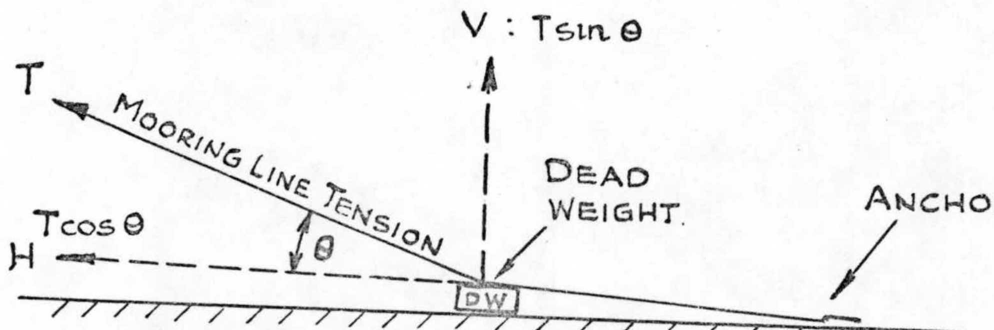


FIG. 6

MOORING LINE No	POINT ON O.W.C.	'PRE TENSION' POSITION							
		L (M)	X (M)	D (M)	θ DEG.	% EXT.	T (kN)	V $T\sin\theta$ (kN)	H $T\cos\theta$ (kN)
1	L	201.2	191.5	62	17.9	29.7	799	245	760
2	U	199.7	188.5	66	19.3	28.5	740	244	698
3	L	197.9	188	62	18.2	26.9	667	207	632
4	U	198.3	187	66	19.4	27.3	686	227	647
5	L	198.9	189	62	18.2	27.8	711	220	674
6	U	198.3	187	66	19.4	27.3	686	227	647
7	L	199.8	190	62	18	28.6	745	230	708
8	U	202.5	191.5	66	19	30.7	848	275	801
9	L	202.5	192.5	62	17.8	30.5	838	256	798
10	U	197.6	186.3	66	19.5	26.8	662	220	623
11	L	197.6	187.7	62	18.3	26.8	662	206	627
12	U	202.1	191	66	19	30.4	833	270	787
13	L	201.2	191.5	62	17.9	29.7	799	245	760
14	U	199.7	188.5	66	19.3	28.5	740	244	698
15	L	197.9	188	62	18.2	26.9	667	207	632
16	U	198.3	187	66	19.4	27.3	686	227	647
17	L	198.9	189	62	18.2	27.8	711	220	674
18	U	198.3	187	66	19.4	27.3	686	227	647
19	L	198.8	190	62	18	28.6	745	230	708
20	U	202.5	191.5	66	19	30.7	848	275	801
21	L	202.2	192.5	62	17.8	30.5	838	256	798
22	U	197.6	186.3	66	19.5	26.8	662	220	623
23	L	197.6	187.7	62	18.3	26.8	662	206	627
24	U	202.1	191	66	19	30.4	833	270	787

FIG 7

MOORING LINE No	POINT ON O.W.C.	MAX. LOAD.		POSITION		+30M EXCURSION.			
		L (M)	X (M)	D (M)	θ DEG.	% EXT.	T (kN)	V TSIN θ (kN)	H TCOS θ (kN)
1	L	231·5	217·7	78·5	19·8	54	3305	1118	3109
2	U	231·5	216·3	82·5	20·8	54	3305	1174	3090
3	L	231·5	217·7	78·5	19·8	54	3305	1118	3109
4	U	231·5	216·3	82·5	20·8	54	3305	1174	3090
5	L	231·5	217·7	78·5	19·8	54	3305	1118	3109
6	U	231·5	216·3	82·5	20·8	54	3305	1174	3090
7	L	231·5	217·7	78·5	19·8	54	3305	1118	3109
8	U	231·5	216·3	82·5	20·8	54	3305	1174	3090
9	L	231·5	217·7	78·5	19·8	54	3305	1118	3109
10	U	231·5	216·3	82·5	20·8	54	3305	1174	3090
11	L	231·5	217·7	78·5	19·8	54	3305	1118	3109
12	U	231·5	216·3	82·5	20·8	54	3305	1174	3090
13	L	231·5	217·7	78·5	19·8	54	3305	1118	3109
14	U	231·5	216·3	82·5	20·8	54	3305	1174	3090
15	L	231·5	217·7	78·5	19·8	54	3305	1118	3109
16	U	231·5	216·3	82·5	20·8	54	3305	1174	3090
17	L	231·5	217·7	78·5	19·8	54	3305	1118	3109
18	U	231·5	216·3	82·5	20·8	54	3305	1174	3090
19	L	231·5	217·7	78·5	19·8	54	3305	1118	3109
20	U	231·5	216·3	82·5	20·8	54	3305	1174	3090
21	L	231·5	217·7	78·5	19·8	54	3305	1118	3109
22	U	231·5	216·3	82·5	20·8	54	3305	1174	3090
23	L	231·5	217·7	78·5	19·8	54	3305	1118	3109
24	U	231·5	216·3	82·5	20·8	54	3305	1174	3090

FIG 8

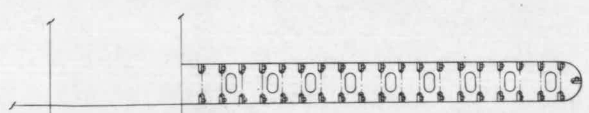
MOORING LINE No	POINT ON O.W.C.	'SLACK' POSITION -30 M EXCURSION							
		L (M)	X (M)	D (M)	θ DEG.	% EXT.	T (kN)	V $T\sin\theta$ (kN)	H $T\cos\theta$ (kN)
1	L	174	168	45.5	15.1	7.8	127.5	33.3	122.6
2	U	168.4	161	49.5	17	3.3	53.9	15.7	51.6
3	L	165.3	159	45.5	15.9	0.8	11.7	3.2	11.2
4	U	165	157.3	49.5	17.4	0	0	0	0
5	L	165.3	159	45.5	15.9	0.87	11.7	3.2	11.2
6	U	165	157.5	49.5	17.4	0.6	9.81	2.9	9.3
7	L	164.2	163	45.5	15.9	3.9	63.7	17.1	61.4
8	U	175.1	168	49.5	16.4	8.7	143.2	40.4	137.3
9	L	174.5	168.5	45.5	15.1	8.2	134.3	35	129.4
10	U	163.9	156.3	49.5	17.5	0	0	0	0
11	L	164.1	157.7	45.5	16	0	0	0	0
12	U	174.6	167.5	49.5	16.4	8.3	136.3	38.4	130.4
13	L	174	168	45.5	15.1	7.8	127.5	33.3	122.6
14	U	168.4	161	49.5	17	3.3	53.9	15.7	51.6
15	L	165.3	159	45.5	15.9	0.8	11.7	3.2	11.2
16	U	165	157.5	49.5	17.4	0	0	0	0
17	L	165.3	159	45.5	15.9	0.87	11.7	3.2	11.2
18	U	165	157.5	49.5	17.4	0.6	9.81	2.9	9.3
19	L	164.2	163	45.5	15.9	3.9	63.7	17.1	61.4
20	U	175.1	168	49.5	16.4	8.7	143.2	40.4	137.3
21	L	174.5	168.5	45.5	15.1	8.2	134.3	35	129.4
22	U	163.9	156.3	49.5	17.5	0	0	0	0
23	L	164.1	157.7	45.5	16	0	0	0	0
24	U	174.6	167.5	49.5	16.4	8.3	136.3	38.4	130.4

FIG 9

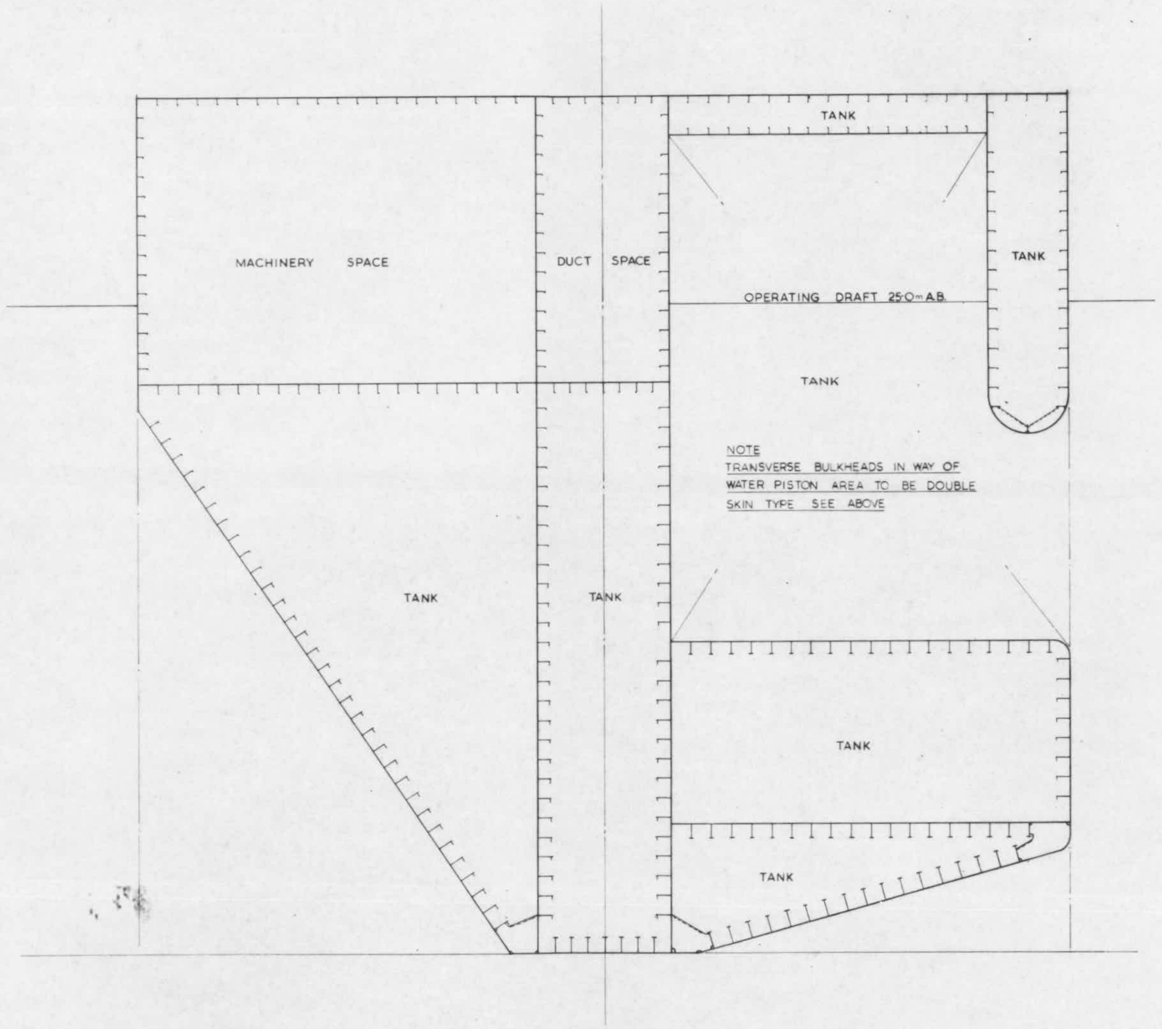
NOTE

TRANSVERSE BULKHEADS:-

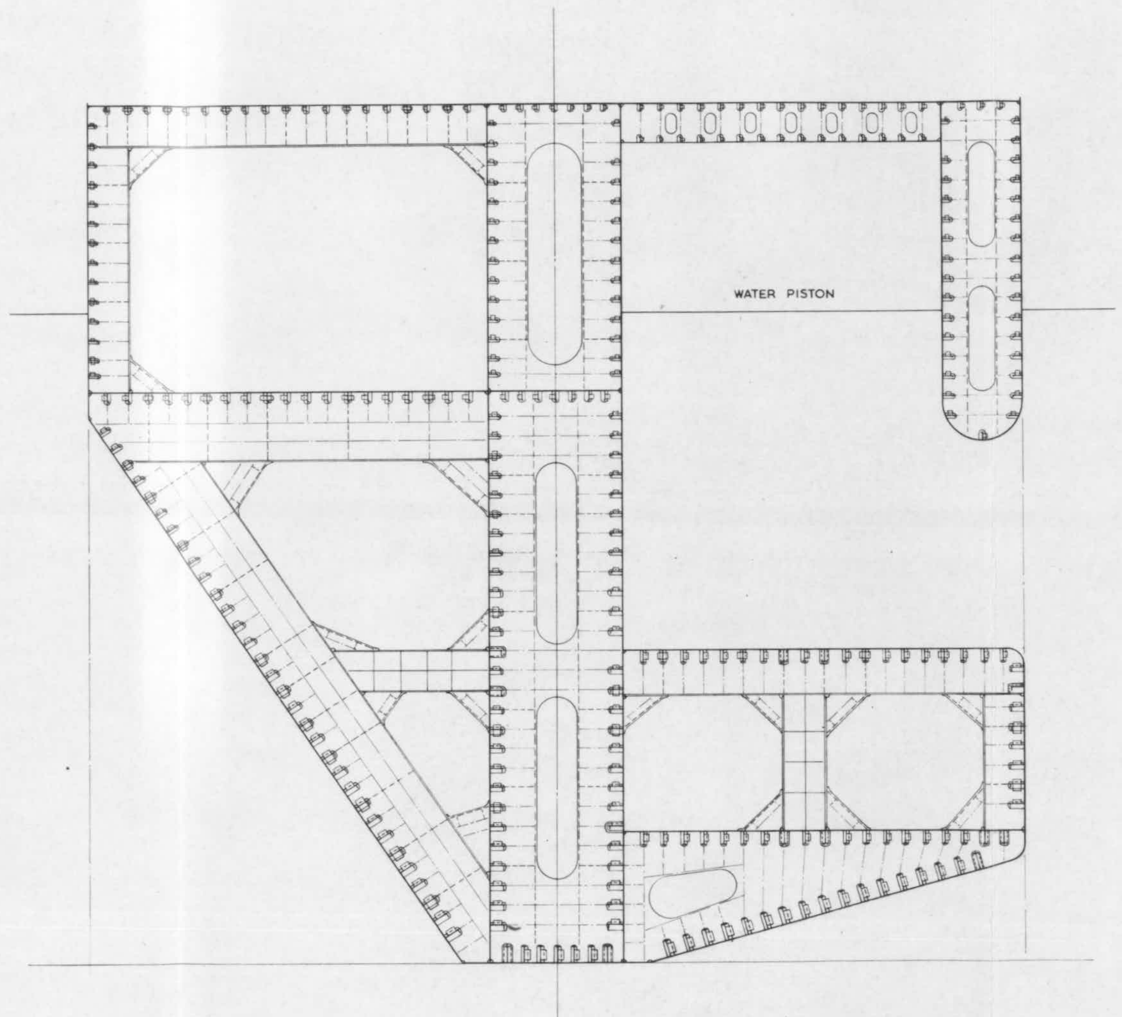
TRANSVERSE BULKHEADS WILL BE OF PLAIN CONSTRUCTION WITH VERTICAL STIFFENERS SUPPORTED BY HORIZONTAL STRINGERS. IN WAY OF WATER PISTON AREA, THE TRANSVERSE BULKHEADS WILL BE OF THE DOUBLE SKIN TYPE WITH VERTICAL STIFFENERS SUPPORTED BY HORIZONTAL DIAPHRAGMS.



DOUBLE SKIN TRANSVERSE BULKHEAD IN WAY OF WATER PISTON AREA



SECTION CLEAR OF TRANSVERSE.



SECTION IN WAY OF TRANSVERSE

ALL TRANSVERSES SPACED 4·0m APART.

NOTES

FIRST STAGE EVALUATION OF POSSIBLE STEELWEIGHT BASED ON LLOYDS RULES AND REGULATIONS FOR THE CLASSIFICATION OF SHIPS.

AN INDICATION OF STEEL CONTENT IS SHOWN IN THE TABLE BELOW.
SCRAP ALLOWANCE IS ABOUT 8·0%.

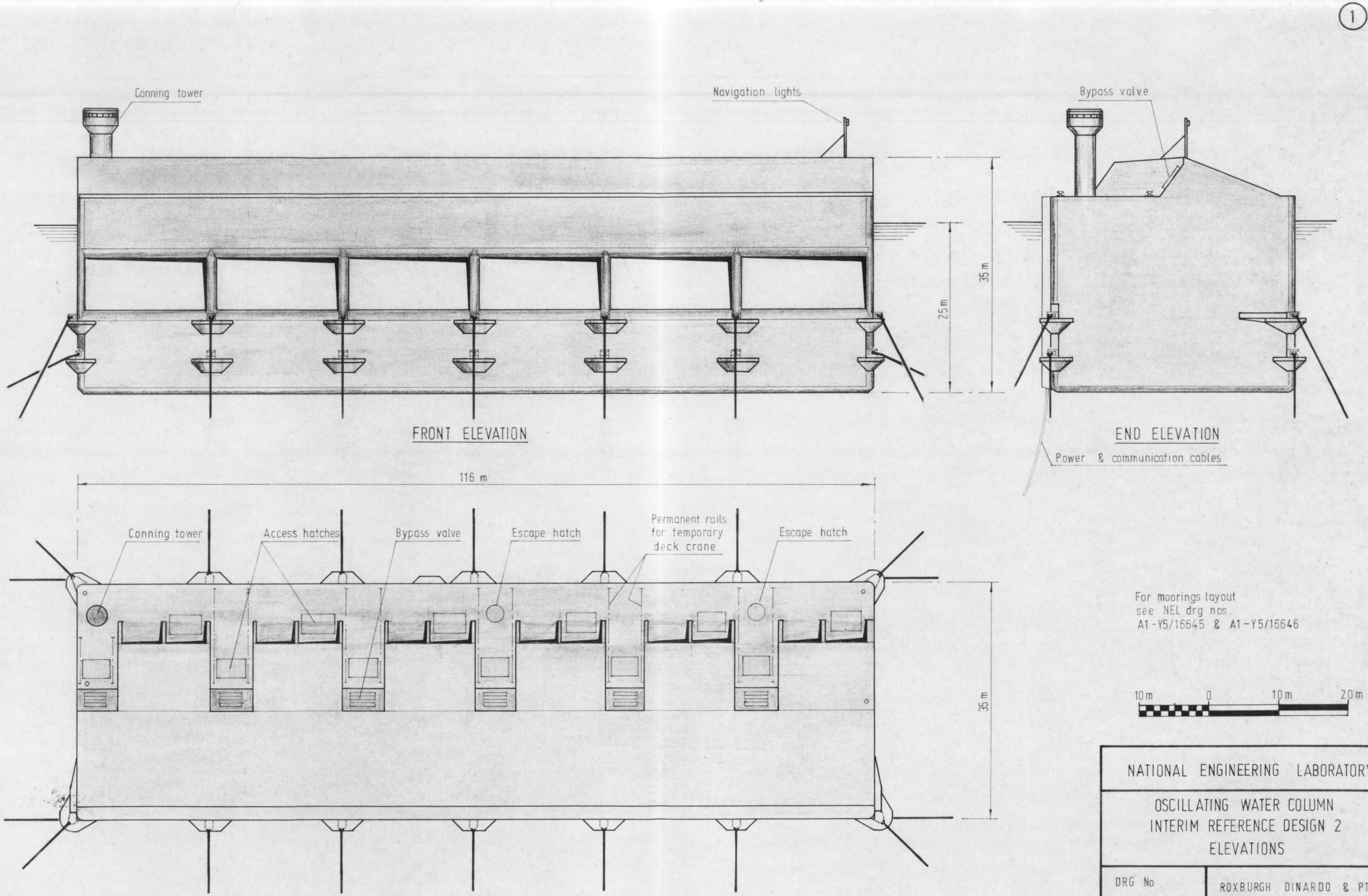
MATERIAL	TYPE/GRADE	THICKNESS RANGE (mm)	FLOATING STEEL WEIGHT (t)	INVOICED STEELWEIGHT (t)
PLATES	MILD STEEL/A.	10 - 25	8020	8717
SECTIONS	MILD STEEL/A.	10 - 25	3980	4326
TOTALS			12,000	13,043

SCOTT LITHGOW LIMITED.
DRAWING NO. WE/SL/2.
PROJECTS. – WAVE ENERGY.

STEEL STRUCTURE ARRANGEMENT.

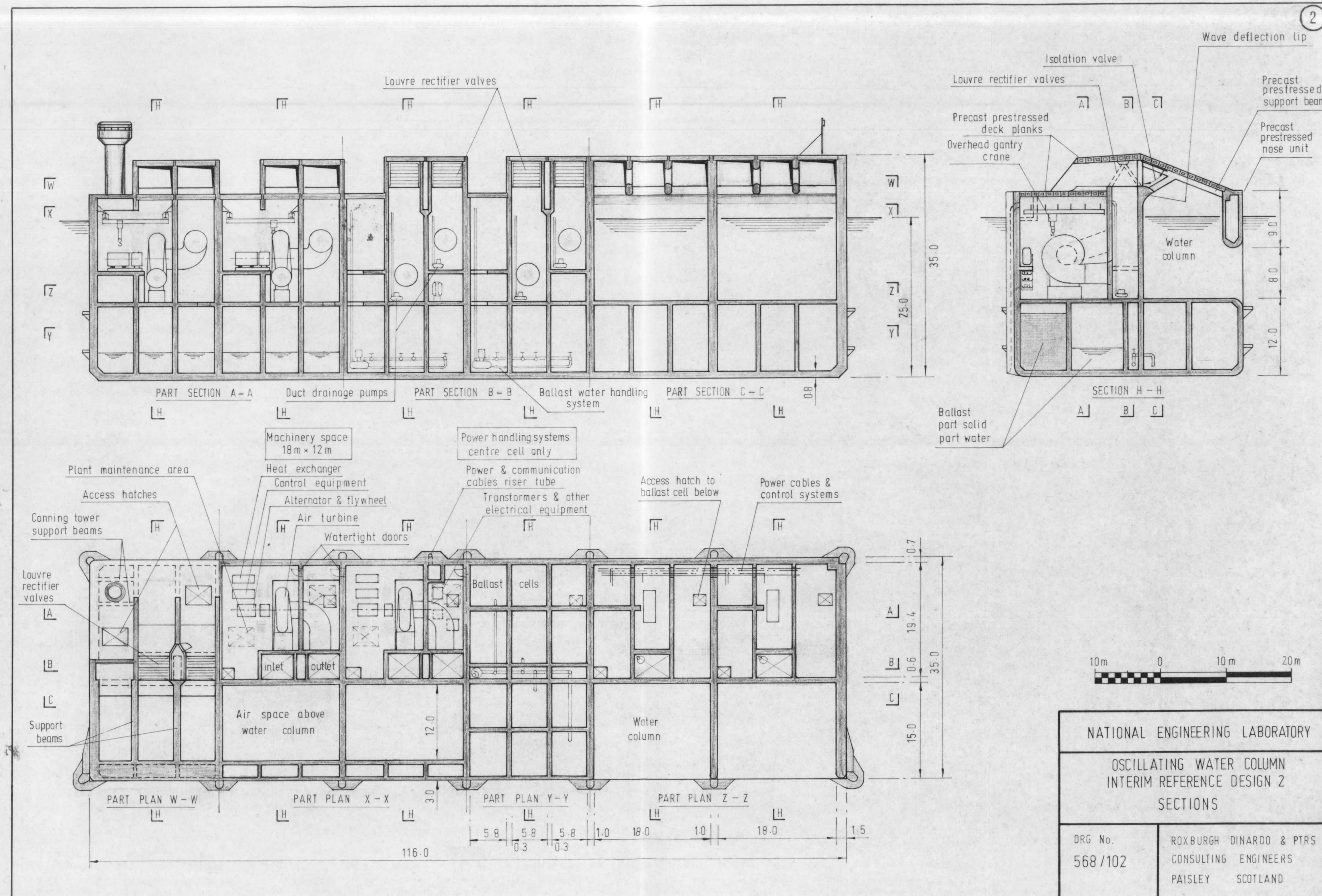
SCALE – 1 : 100.

DRAWN BY –	J.W. MCVEAN	7/8/78



For moorings layout see NEL drg nos. A1-Y5/16645 & A1-Y5/16646

NATIONAL ENGINEERING LABORATORY	
OSCILLATING WATER COLUMN INTERIM REFERENCE DESIGN 2 ELEVATIONS	
DRG No 568/101	ROXBURGH DINARDO & PTRS CONSULTING ENGINEERS PAISLEY SCOTLAND

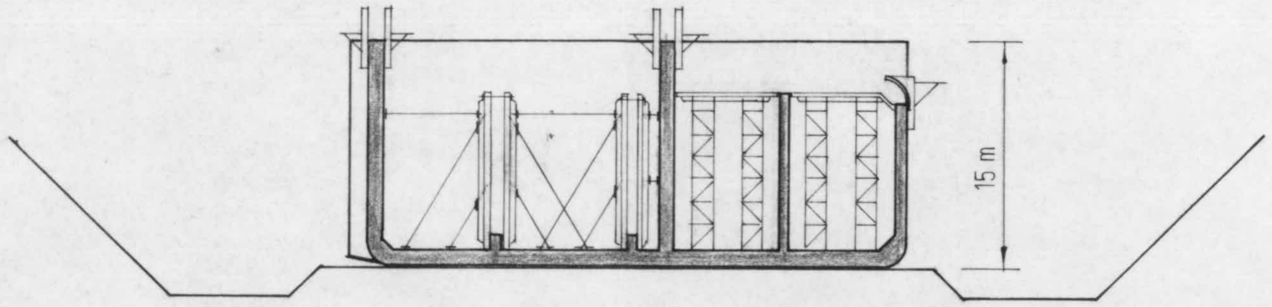


NATIONAL ENGINEERING LABORATORY

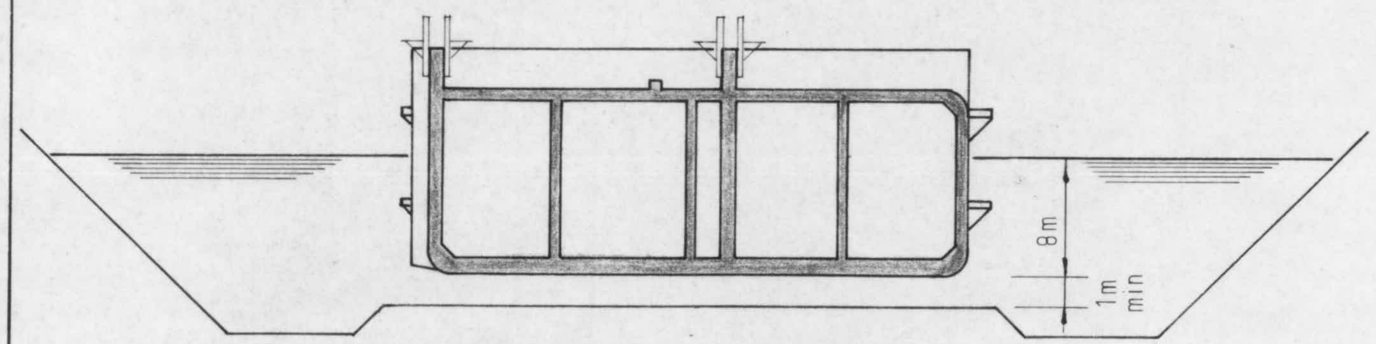
OSCILLATING WATER COLUMN
INTERIM REFERENCE DESIGN 2
SECTIONS

DRG No. 568/102

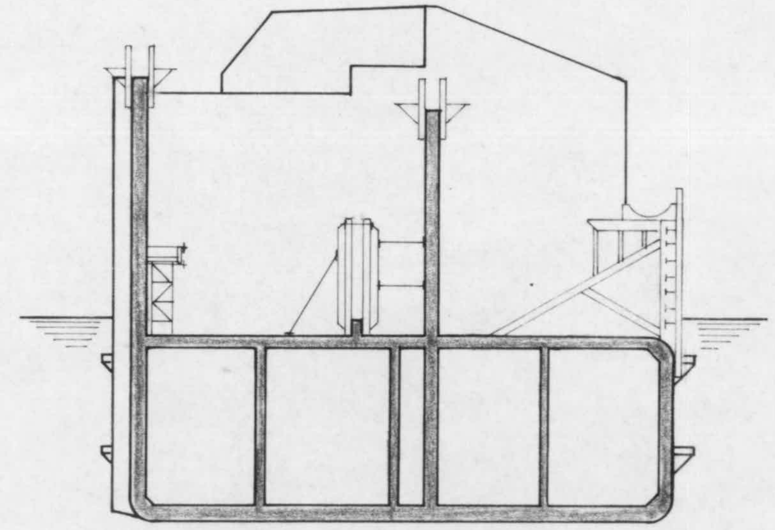
ROXBURGH DINARDO & PTRS
CONSULTING ENGINEERS
PAISLEY SCOTLAND



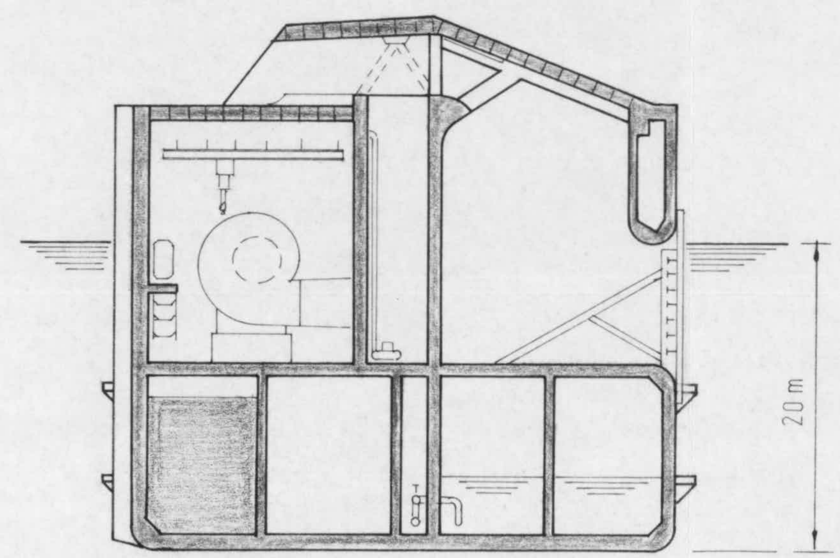
1. Lower caisson constructed in drydock using slipforming for the main vertical walls and insitu shuttering for slabs and minor walls.



2. Outer walls completed to 15 m height. Drydock flooded and structure towed out to deep water construction site.



3. Steel bulkhead erected to close mouth of water column chamber. Slipforming and insitu concrete work continued.



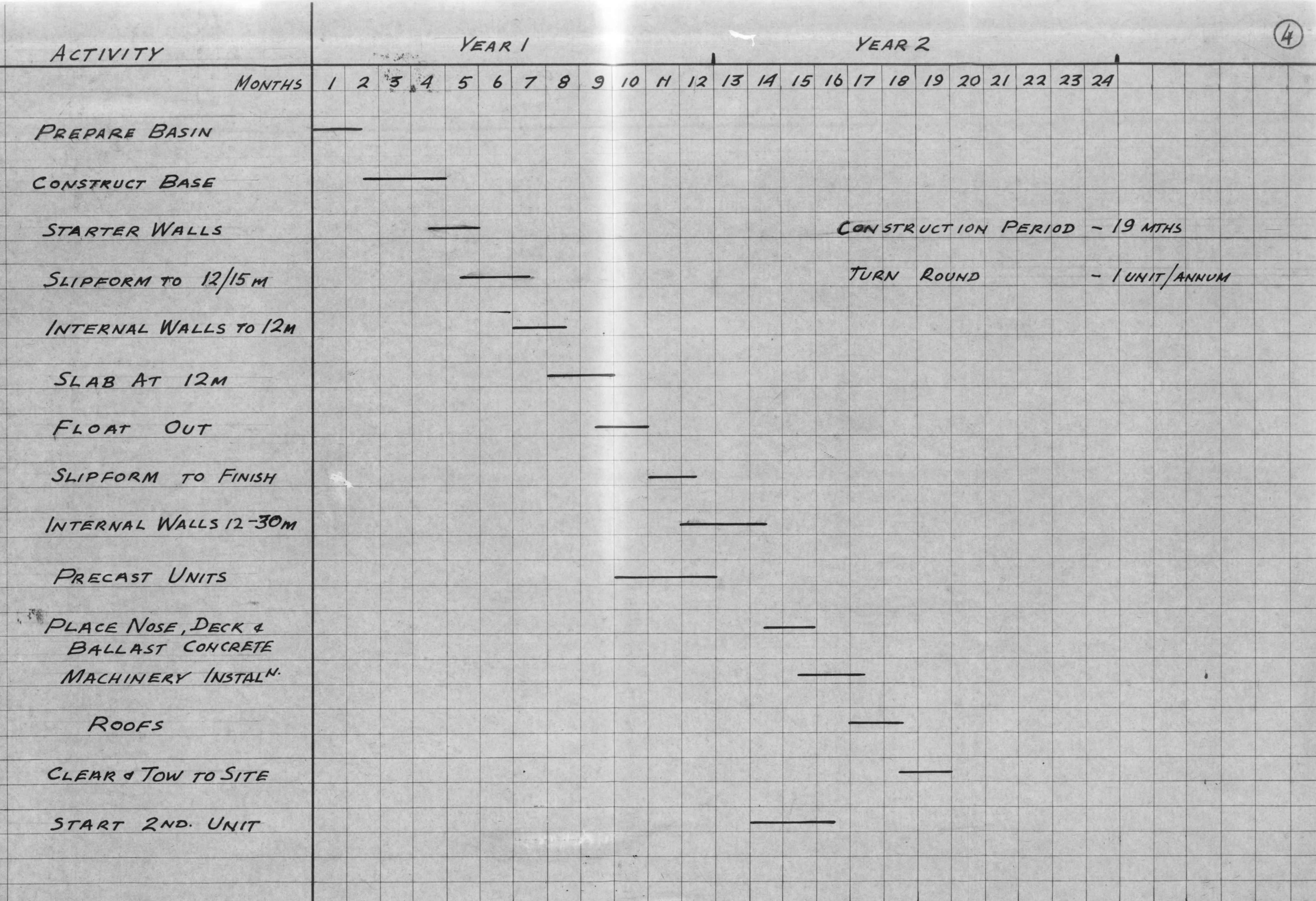
4. Precast units added, structure completed and equipment installed. Permanent solid and temporary trim ballast added prior to tow to final location. Final trim ballast added after removal of the bulkhead.

NATIONAL ENGINEERING LABORATORY

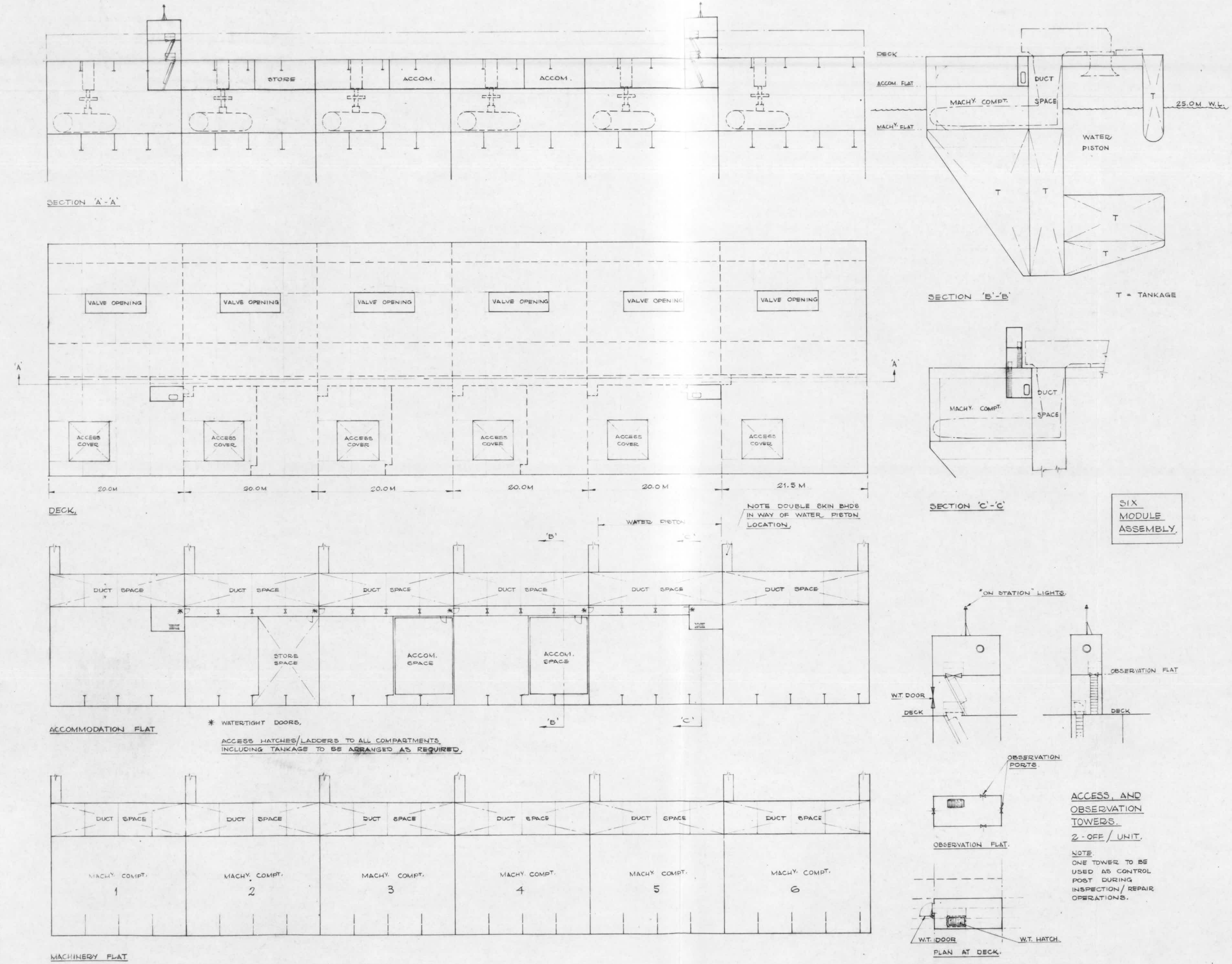
OSCILLATING WATER COLUMN
INTERIM REFERENCE DESIGN 2
CONSTRUCTION SEQUENCE

DRG No
568/103

ROXBURGH DINARDO & PTRS
CONSULTING ENGINEERS
PAISLEY SCOTLAND



ROXBURGH DINARDO & PARTNERS CONSULTING ENGINEERS	MIRREN HOUSE 6 MAXWELL STREET PAISLEY TEL 041-887-0421	PROGRAMME FOR CONCRETE UNITS	Job No. 568/104	Programme No. 1	Revision



WAVE ENERGY UNITS

① EACH UNIT TO BE OUTFITTED WITH REQUIRED EQUIPMENT WHICH WILL INCLUDE.

a/ SEA STATION MOORING FITTINGS.
b/ TOWAGE FITTINGS.
c/ SEA STATION NAVIGATION LIGHTS.
d/ STORM RAILS TO DECK WORKING/MAINTENANCE AREAS.

② UNIT UNMANNED AT SEA STATION.

ACCOMMODATION SPACE IS TO PROVIDE SHELTER FOR NORMAL WORKING & SURVIVAL CONDITIONS.

THE MOORED WAVE ENERGY UNIT WILL BE UNMANNED EXCEPT ON INSPECTION, REPAIR & MAINTENANCE OCCASIONS.

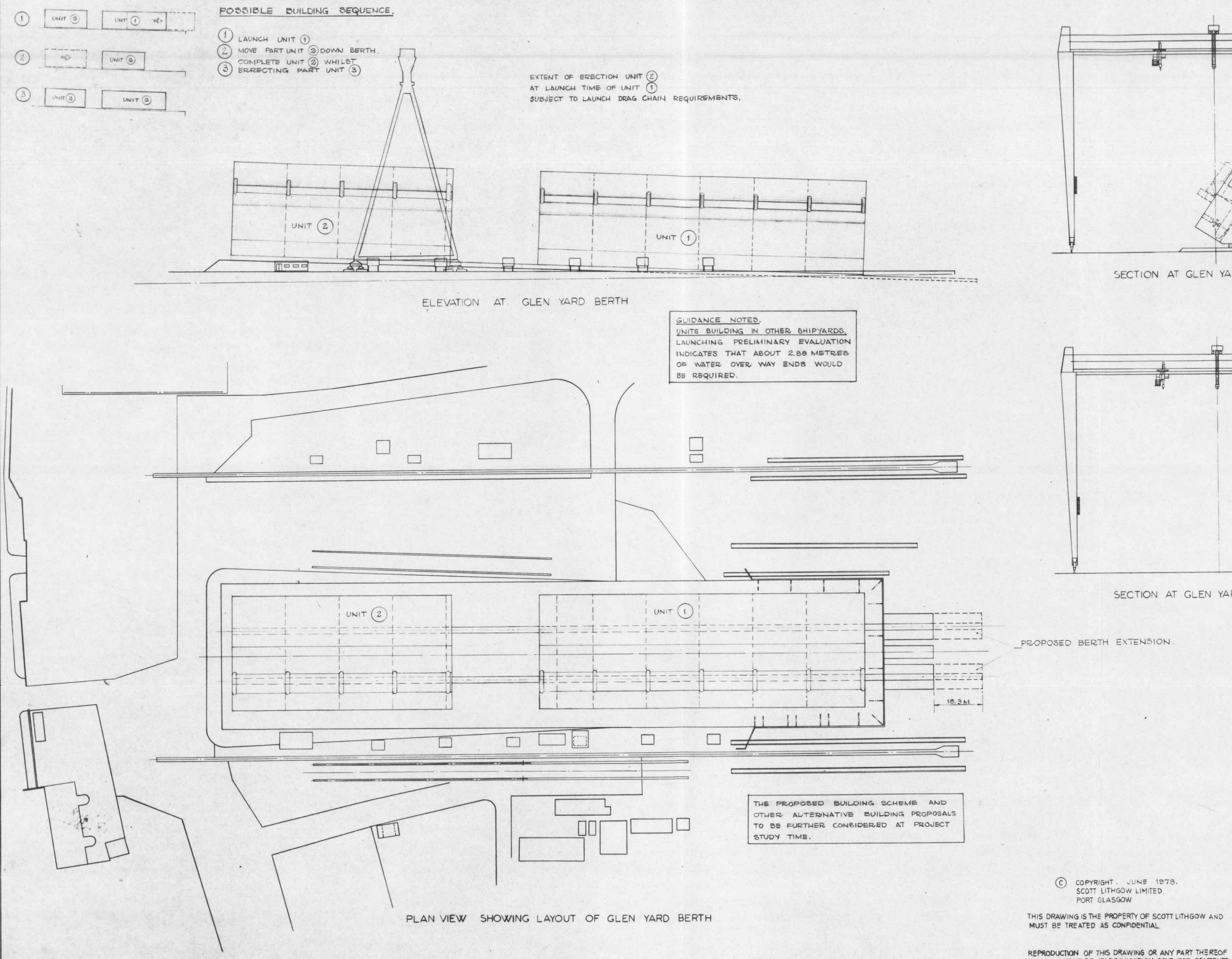
SCOTT LITHGOW LIMITED
DRAWING NO. W.E./S.L./1

PROJECTS. - WAVE ENERGY. (N.E.L.)

OUTLINE GENERAL ARRANGEMENT OF WAVE ENERGY UNIT.

SCALE :- 1 : 200

DRAWN BY	J. MEEK.	22.6.78

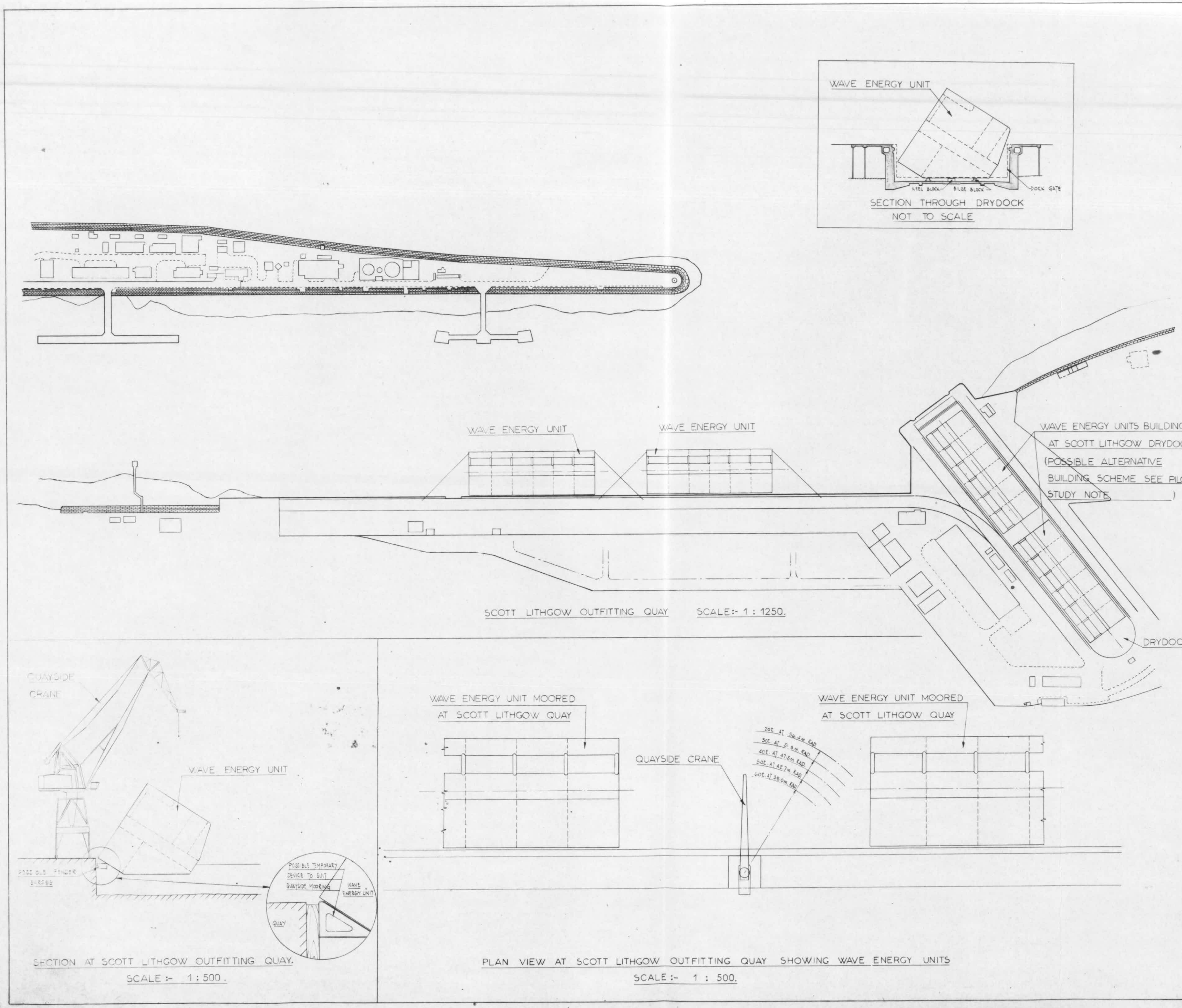


SCOTT LITHGOW LIMITED
DRAWING NO. W.E./S.L./3.
PROJECTS - WAVE ENERGY (N.E.L)

W.E. UNIT BUILDING SCHEME
AT SCOTT LITHGOW'S
GLEN YARD BERTH.

SCALE:- 1:500

DRAWN BY	U. MEEK.	3.6.78
CHECKED BY		



THIS DRAWING ILLUSTRATES :-

1. WAVE ENERGY UNITS AT QUAYSIDE AFTER LAUNCH BEFORE TOWAGE TO BALLASTING SITE.

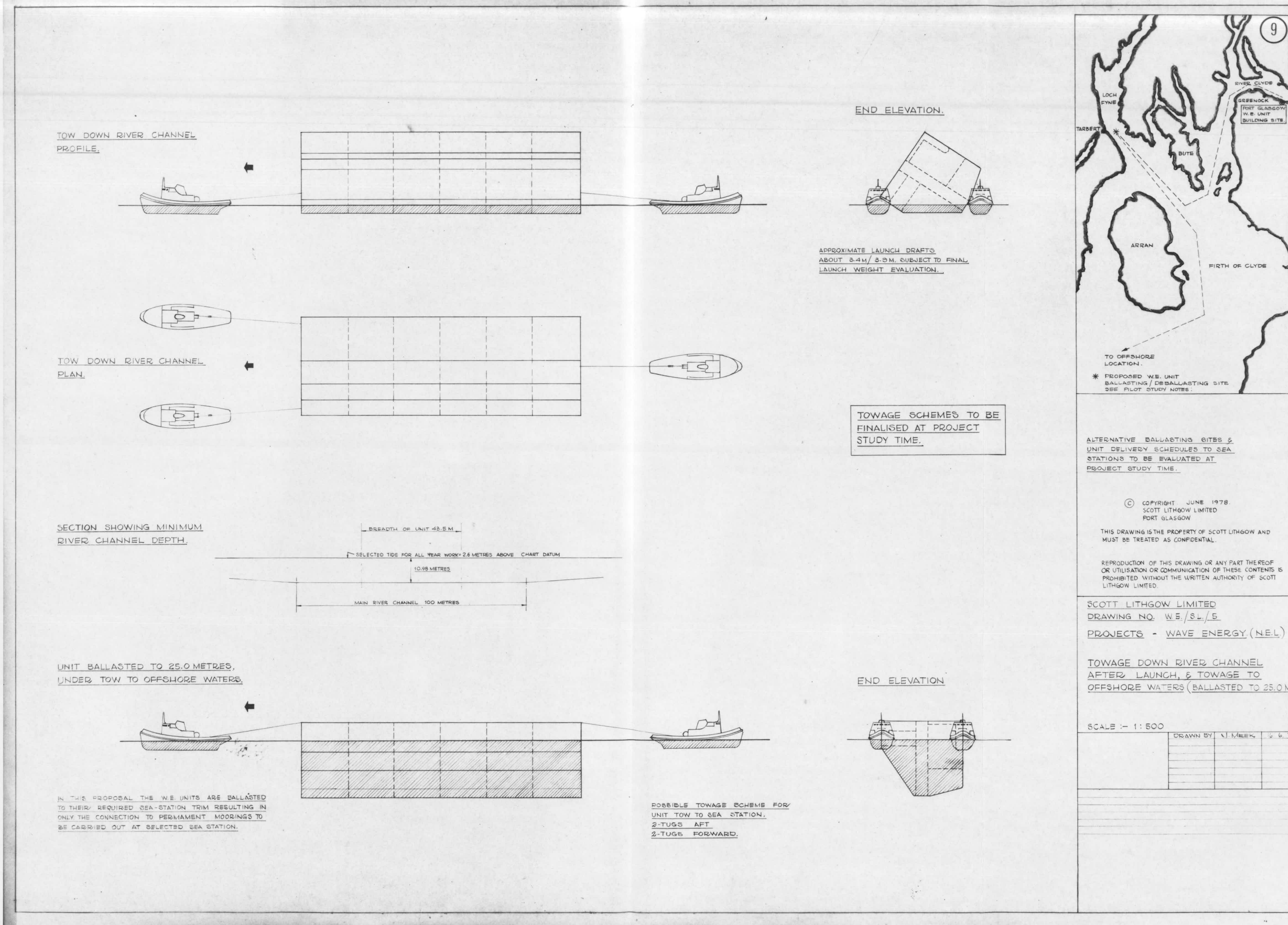
2. BUILDING IN DRY DOCK :-
DEPENDING ON FINALISED WAVE ENERGY UNIT SHAPE AN INDICATION OF GATE WIDTH OF 145 FEET WOULD BE REQUIRED.

SCOTT LITHGOW LIMITED
DRAWING NO. WE/SL/4
PROJECTS :- WAVE ENERGY

WAVE ENERGY UNIT MOORED AT
SCOTT LITHGOW OUTFITTING QUAY

SCALES :- AS MARKED

DRAWN BY	J. WILSON	19.6.78


9
TOW DOWN RIVER CHANNEL PROFILE.
END ELEVATION.
APPROXIMATE LAUNCH DRAFTS ABOUT 3.4M/3.9M. SUBJECT TO FINAL LAUNCH WEIGHT EVALUATION.
TOW DOWN RIVER CHANNEL PLAN.
TOWAGE SCHEMES TO BE FINALISED AT PROJECT STUDY TIME.
SECTION SHOWING MINIMUM RIVER CHANNEL DEPTH.
BREADTH OF UNIT 43.5 M
SELECTED TIDE FOR ALL YEAR WORK= 2.6 METRES ABOVE CHART DATUM
10.98 METRES
MAIN RIVER CHANNEL 100 METRES
UNIT BALLASTED TO 25.0 METRES, UNDER TOW TO OFFSHORE WATERS.
END ELEVATION
IN THIS PROPOSAL THE W.E. UNITS ARE BALLASTED TO THEIR REQUIRED SEA-STATION TRIM RESULTING IN ONLY THE CONNECTION TO PERMAMENT MOORINGS TO BE CARRIED OUT AT SELECTED SEA STATION.
POSSIBLE TOWAGE SCHEME FOR UNIT TOW TO SEA STATION. 2-TUGS AFT 2-TUGS FORWARD.
LOCH FYNE
TARBERT
BUTE
RIVER CLYDE
GREENOCK
PORT GLASGOW W.E. UNIT BUILDING SITE.
ARRAN
FIRTH OF CLYDE
TO OFFSHORE LOCATION.
* PROPOSED W.E. UNIT BALLASTING / DEBALLASTING SITE SEE PILOT STUDY NOTES.
ALTERNATIVE BALLASTING SITES & UNIT DELIVERY SCHEDULES TO SEA STATIONS TO BE EVALUATED AT PROJECT STUDY TIME.
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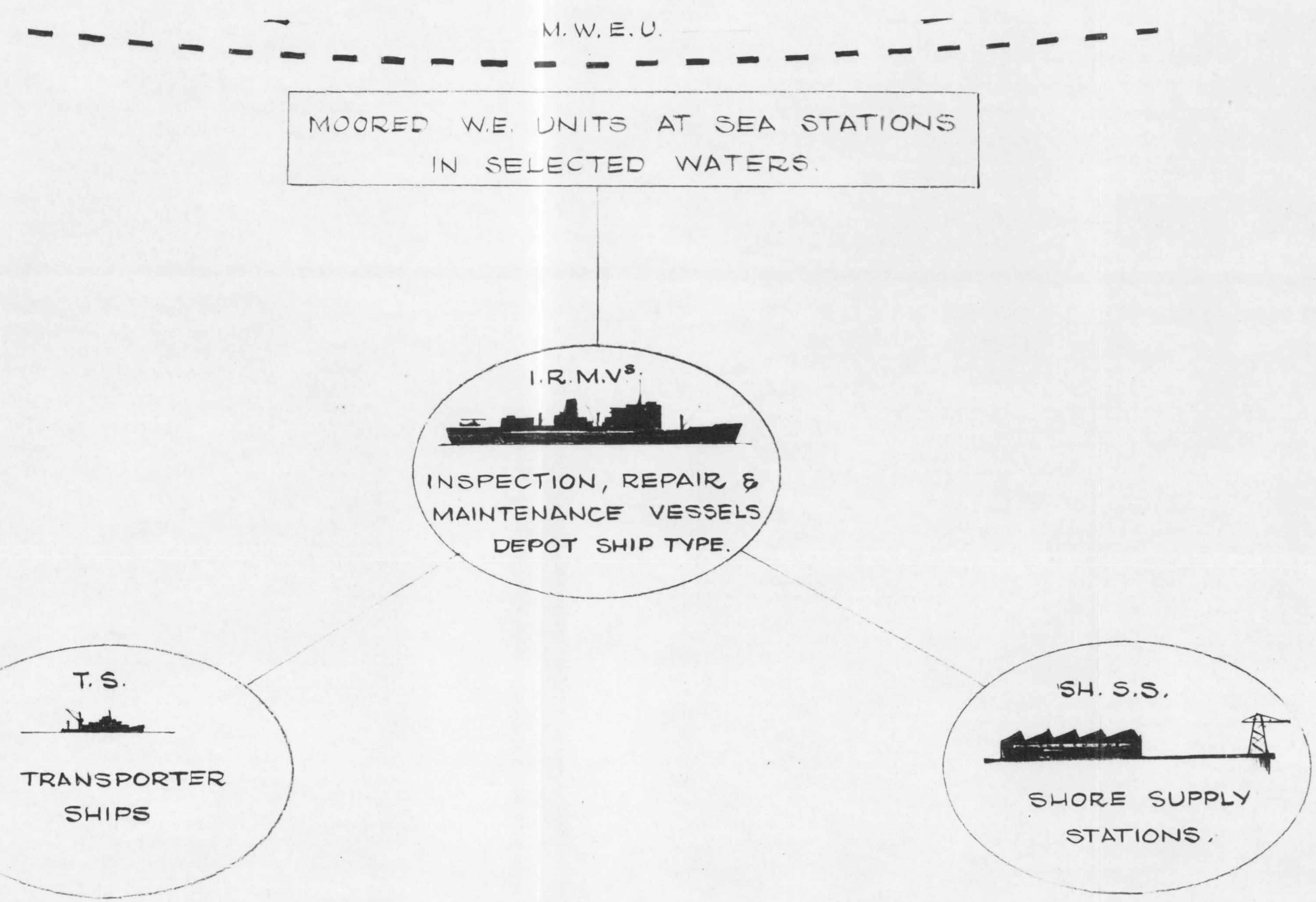
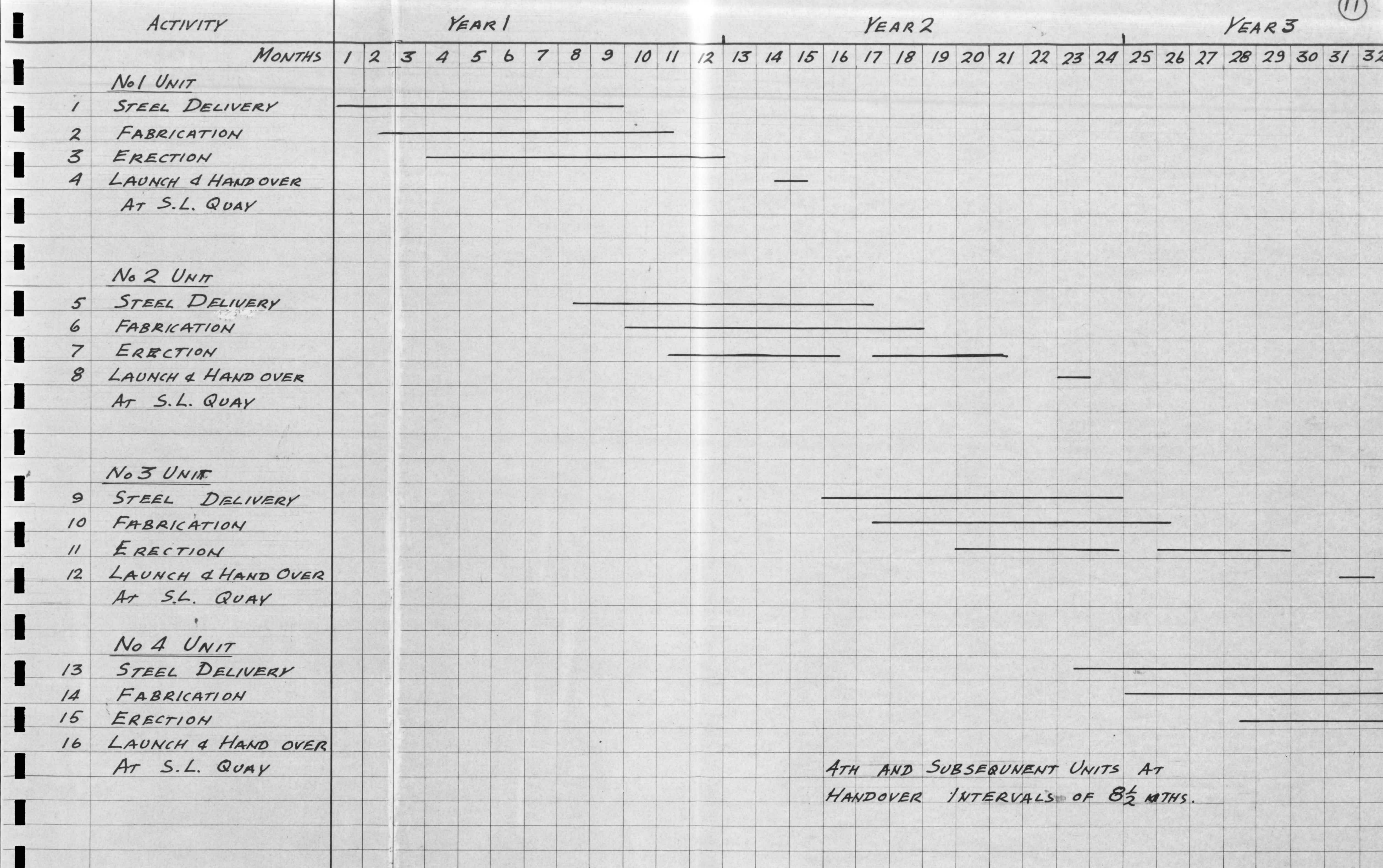
SCOTT LITHGOW LIMITED
DRAWING NO. W.E./S.L./5
PROJECTS - WAVE ENERGY (N.E.L.)
TOWAGE DOWN RIVER CHANNEL AFTER LAUNCH, & TOWAGE TO OFFSHORE WATERS (BALLASTED TO 25.0 M)
SCALE :- 1 : 500
DRAWN BY J. MEEK 16 6 78

POSSIBLE ORGANISATION STRUCTURE FOR WAVE ENERGY SUPPORT SERVICE



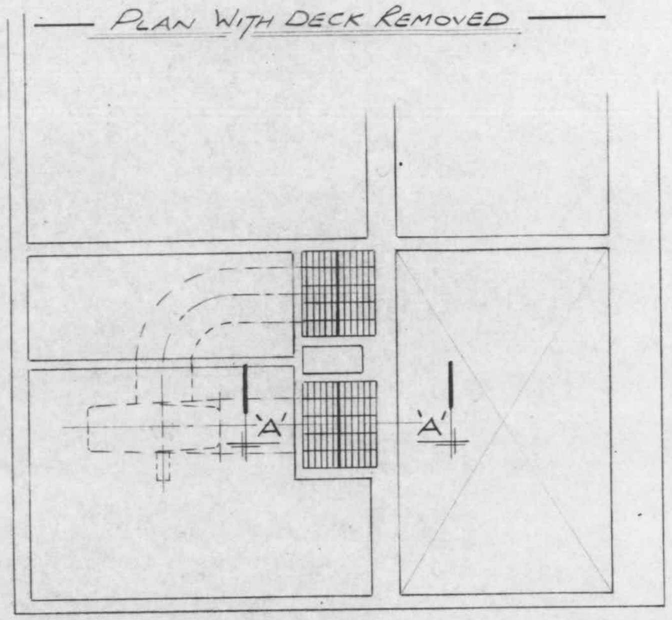


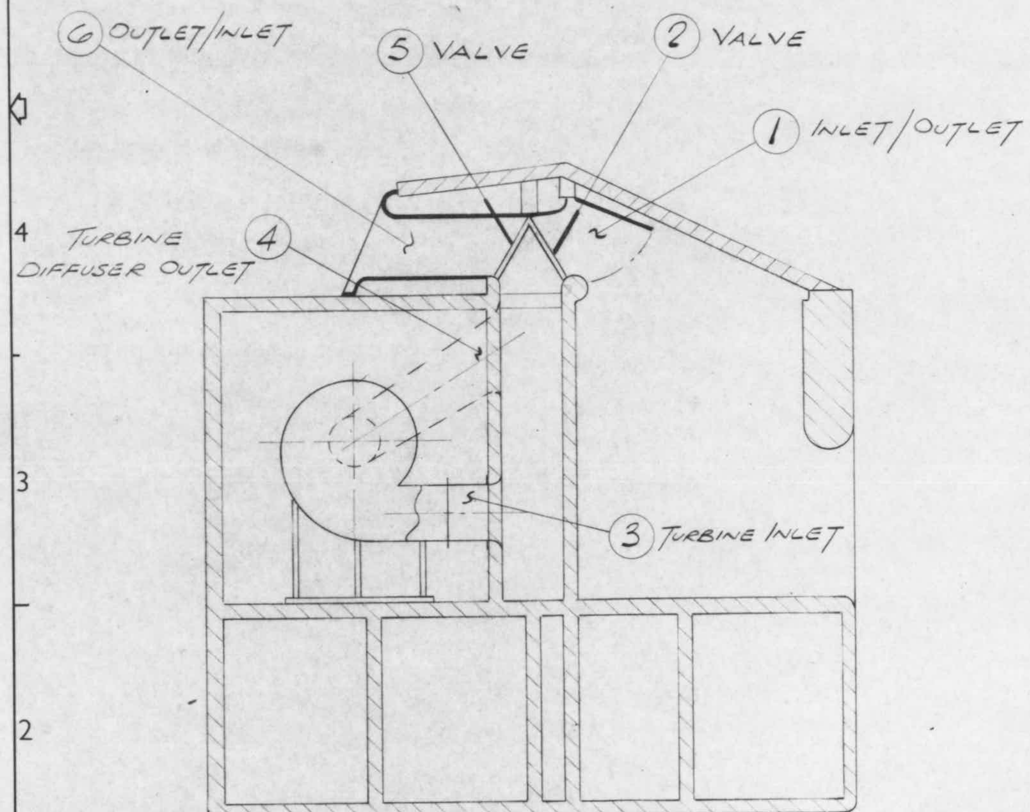
ROXBURGH DINARDO & PARTNERS CONSULTING ENGINEERS	MIRREN HOUSE 6 MAXWELL STREET PAISLEY TEL 041-887-0421	STEEL UNITS SERIES BUILDING PROGRAMME PREPARED BY SCOTT LITHGOW LTD.	Job No.	Programme No.	Revision

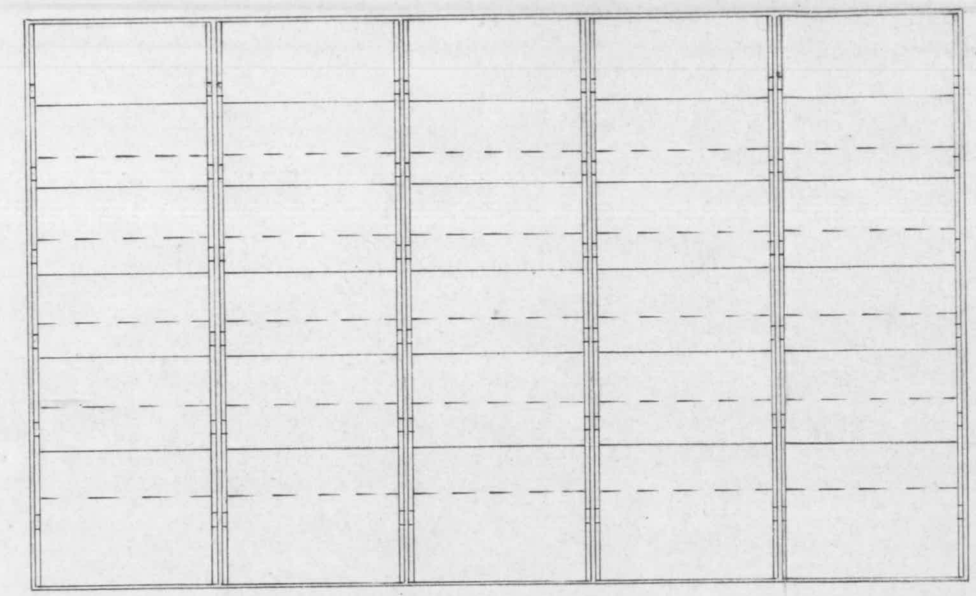
DRAWING No. A1-YS/16658 | DO NOT SCALE. DIMENSIONS IN UNLESS OTHERWISE STATED. THIRD ANGLE PROJECTION. SYMBOLS TO B.S. 308. UNTOLERANCED MACHINED DIMENSIONS TO ±

12

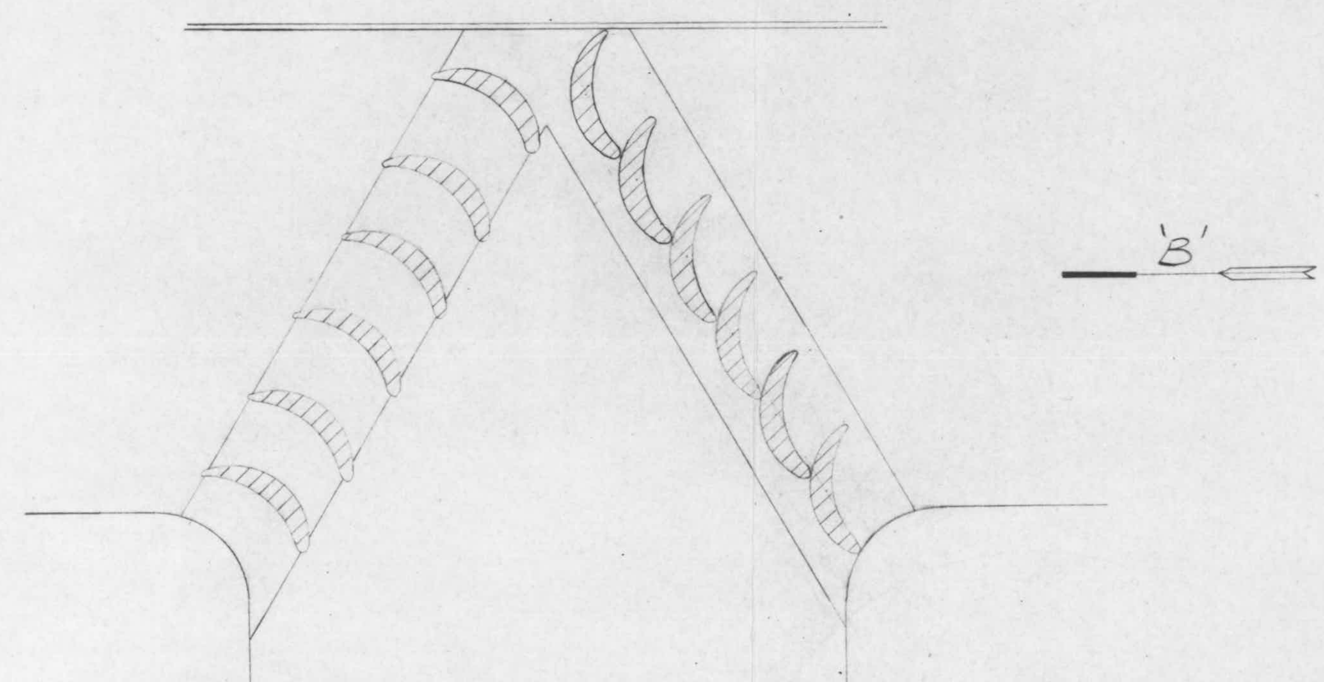
PLAN WITH DECK REMOVED







VIEW ON ARROW 'B'



ENLARGED SECT'N THRU' 'A'-'A'

DATE	MODIFICATION	ZONE	SIGN

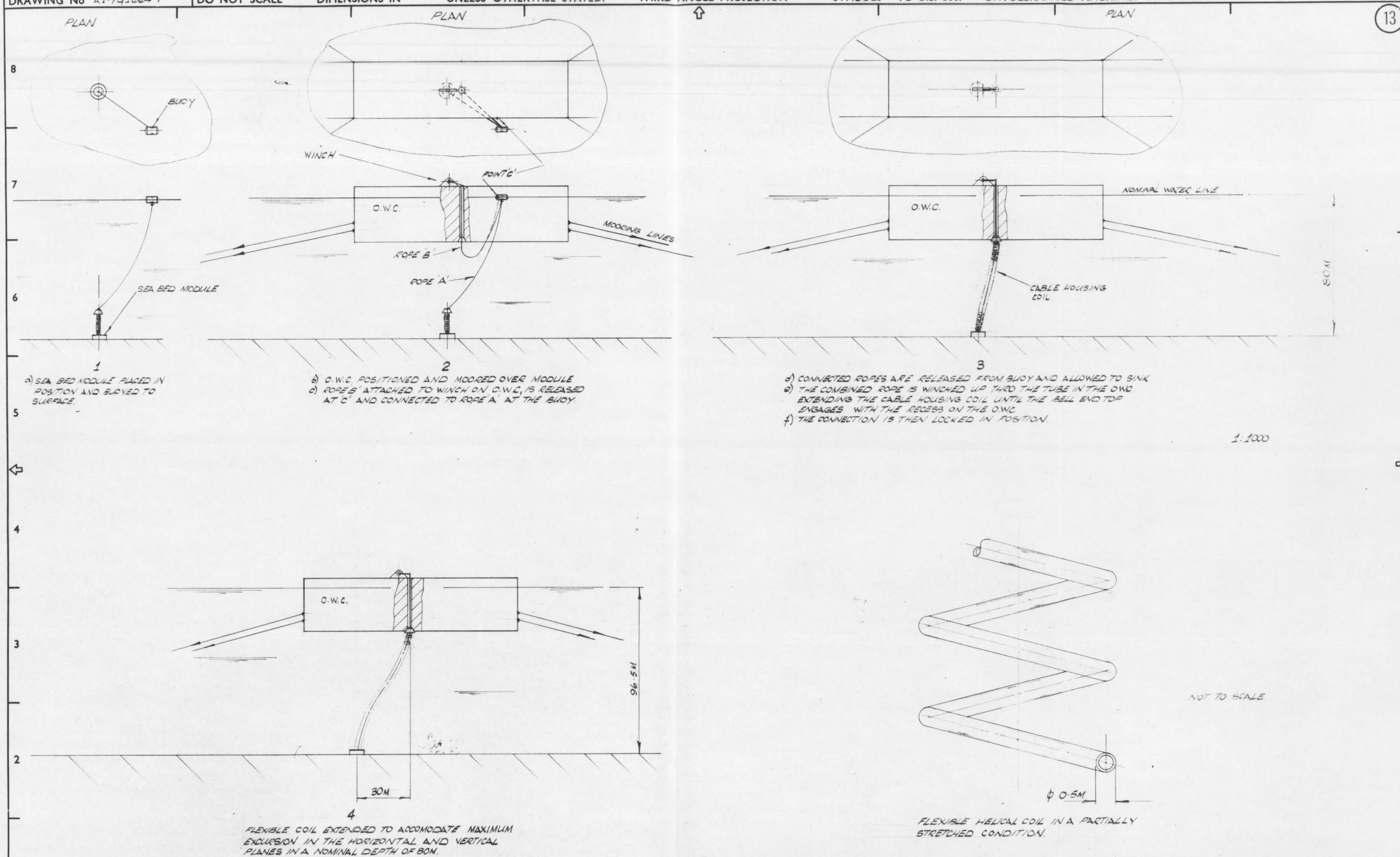
PART No.					
ASSY No.					
No. OFF					
MATERIAL					

DATE	PROJECT No.	JOB No.
JULY '78	YS DEY 2	
DRN.	TRD.	CHK'D.	APP.
MAX-D			

TITLE
100 MW O.W.C. POWER STATION
RECTIFYING VALVES
FRAME 554mm x 801mm

NATIONAL ENGINEERING LABORATORY,
EAST KILBRIDE, GLASGOW.
DRAWING No.
A1-YS/16658

DRAWING No A1-Y5/16647 | DO NOT SCALE | DIMENSIONS IN | UNLESS OTHERWISE STATED. | THIRD ANGLE PROJECTION | SYMBOLS TO B.S. 308. | UNTOLERANCED MACHINED DIMENSIONS TO ±



DATE	MODIFICATIONS	ZONE	SIGN	PART No	DATE	PROJECT No	JOB No	TITLE
				ASSY No	JULY 78	Y5DEY2		100 MW O.W.C. POWER STATION SCHEMATIC DESIGN OF POSITIONING AND CONNECTING OF POWER TAKE OFF
				No OFF	DRN	TRD.	CHK'D.	APP.
				MATERIAL	W.A.L.			FRAME 554 mm. x 801 mm.

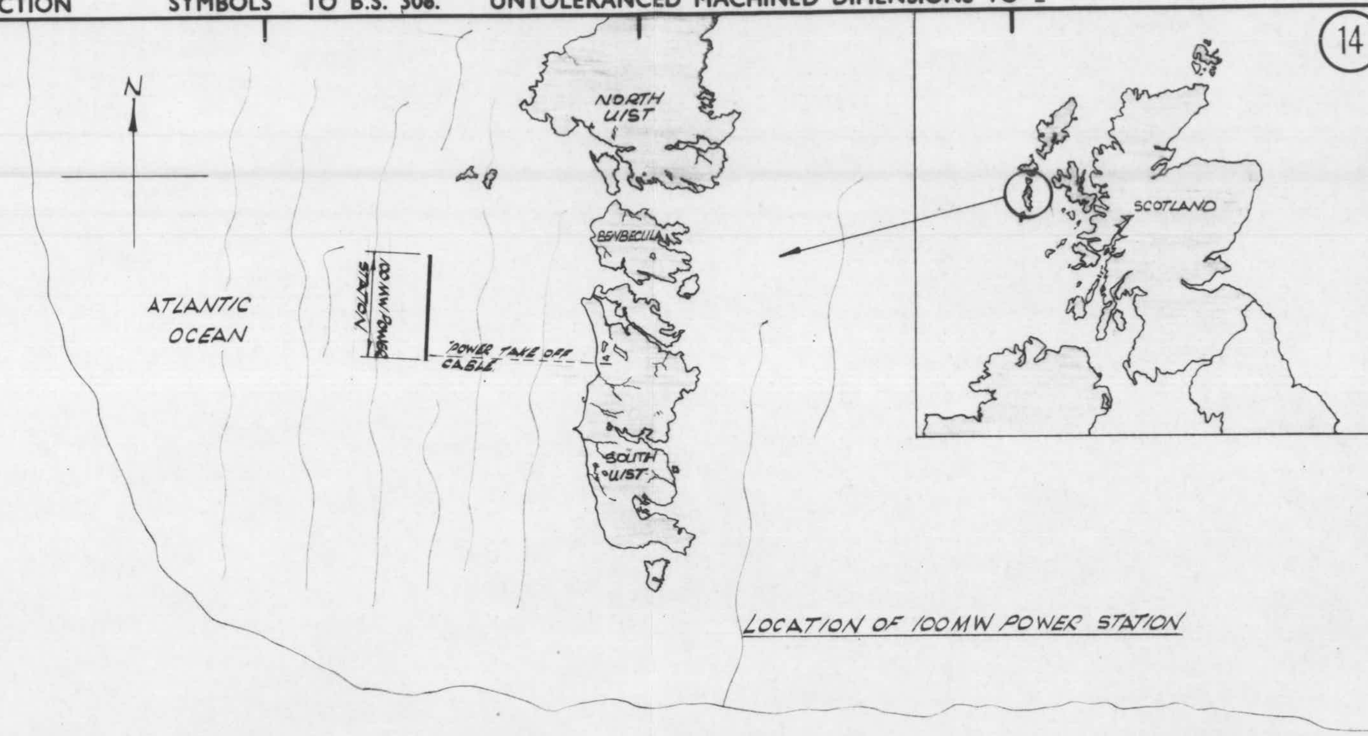
NATIONAL ENGINEERING LABORATORY
EAST KILBRIDE, GLASGOW.
DRAWING No A1-Y5/16647

DRAWING No A1-Y5/16G45 | DO NOT SCALE | DIMENSIONS IN | UNLESS OTHERWISE STATED. | THIRD ANGLE PROJECTION | SYMBOLS TO B.S. 308. | UNTOLERANCED MACHINED DIMENSIONS TO ±

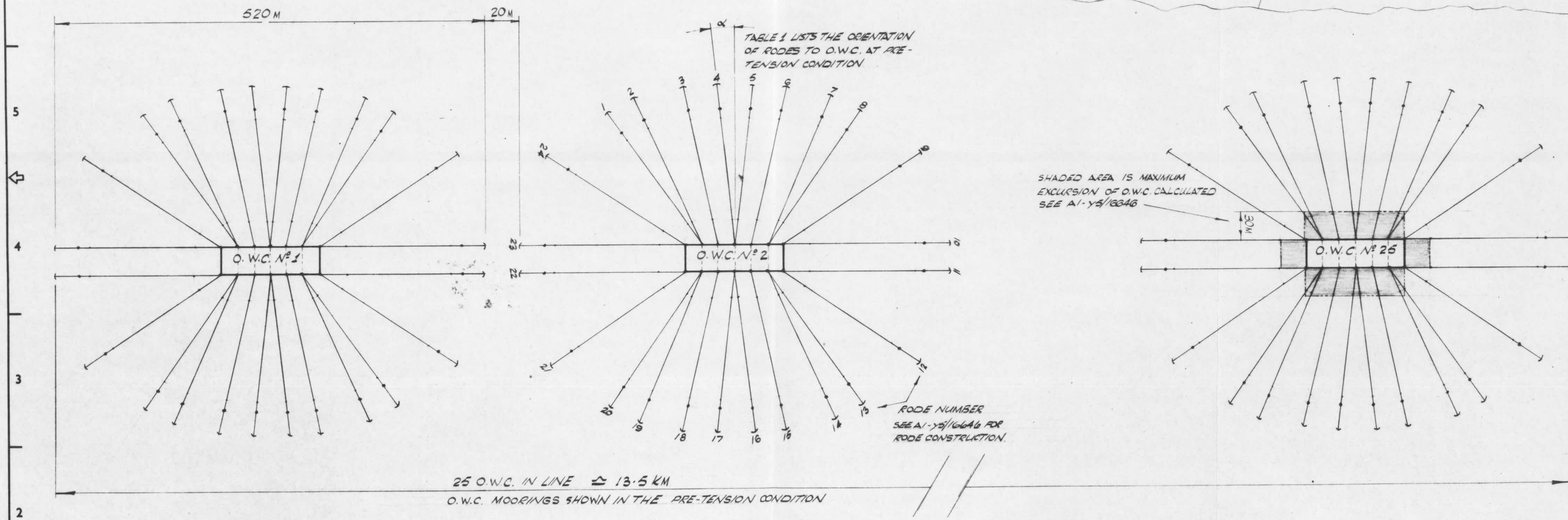
(14)

- TABLE 1 -

RODE	ANGLE ORIENTATION
1	$\alpha = 34.5°$
2	" = 23.5°
3	" = 12°
4	" = 6°
5	" = 6°
6	" = 12.5°
7	" = 23°
8	" = 34°
9	" = 56°
10	" = 90°
11	" = 90°
12	" = 56°
13	" = 34.5°
14	" = 25.5°
15	" = 12°
16	" = 6°
17	" = 6°
18	" = 12.5°
19	" = 23°
20	" = 34°
21	" = 56°
22	" = 90°
23	" = 90°
24	" = 56°



LOCATION OF 100MW POWER STATION



O.W.C. MOORINGS SHOWN IN THE PRE-TENSION CONDITION

1 : 2500

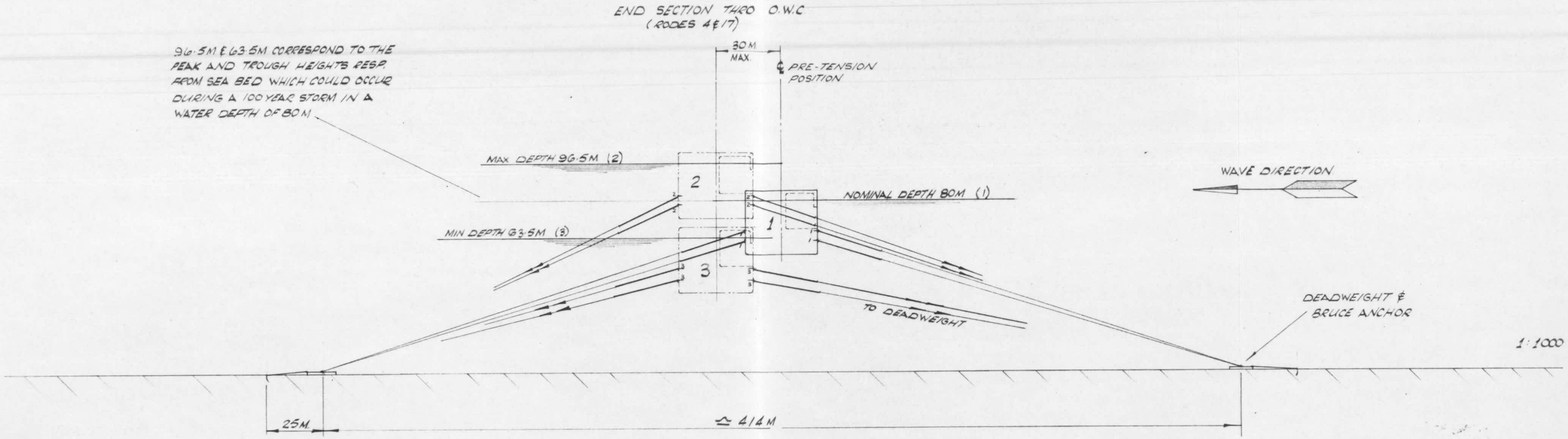
DATE	MODIFICATIONS	ZONE	SIGN	PART No				DATE	PROJECT No	JOB No	TITLE
				ASSY No				JULY 78	Y5DEY 2		100MW O.W.C. POWER STATION REFERENCE MOORING DESIGN LOCATION PLAN
				No OFF				DRN	TRD.	CHK'D.	APP.
				MATERIAL				W.A.L.			

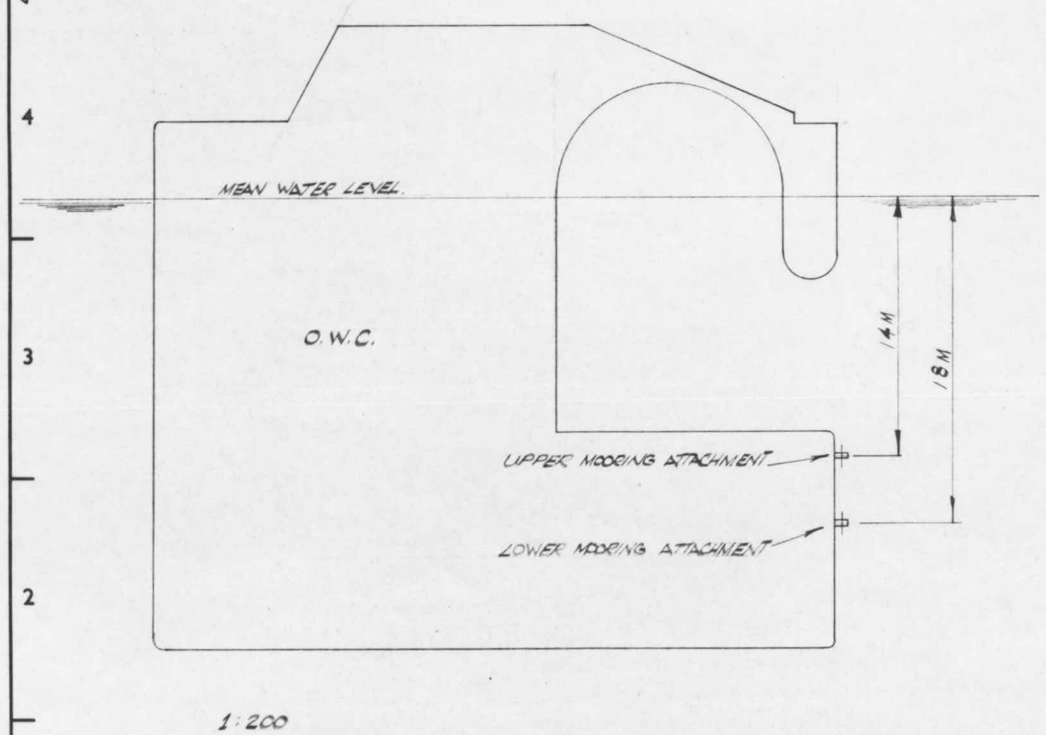
FRAME 554 mm. x 801 mm.

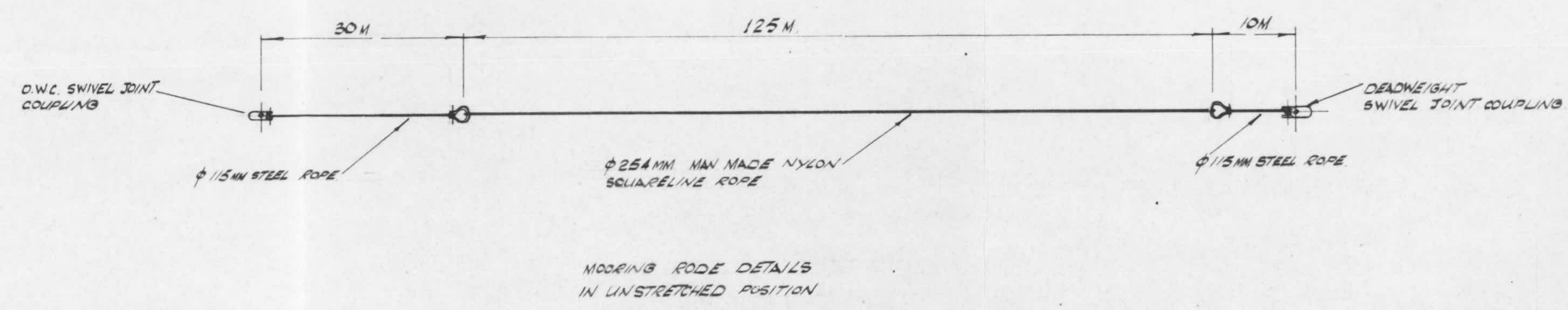
NATIONAL ENGINEERING LABORATORY
EAST KILBRIDE, GLASGOW.

DRAWING No A1-Y5/16G45

DRAWING No A1·YS/16646 | DO NOT SCALE | DIMENSIONS IN | UNLESS OTHERWISE STATED. | THIRD ANGLE PROJECTION | SYMBOLS TO B.S. 308. | UNTOLERANCED MACHINED DIMENSIONS TO ±







DATE	MODIFICATIONS	ZONE	SIGN	PART No
				ASSY No
				No OFF
				MATERIAL

DATE	PROJECT No	JOB No
JULY 78	YSDEY 2	
DRN	TRD.	CHK'D.	APP.
W.A.L			

TITLE
100 MW O.W.C. POWER STATION
REFERENCE MOORING DESIGN
RODES AND ATTACHMENTS

FRAME 554 mm. x 801 mm.

NATIONAL ENGINEERING LABORATORY
EAST KILBRIDE, GLASGOW.

DRAWING No
A1·YS/16646